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Complete Fault Rock Distribution Analysis along the Hirabayashi NIED Core Penetrating the Nojima Fault at 1,140m Depth, Awaji Island, Southwest Japan

By

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Abstract

The distribution and petrological characteristics of fault rocks in a shallow fault zone (1,140m depth) of granitic origin were examined in a fault zone in the NIED (the National Research Institute for Earth Science and Disaster Prevention) drill core (NIED core) penetrating the Nojima fault, which was activated during the 1995 Hyogo-ken Nanbu Earthquake (M=7.2). The NIED core consists of granodiorite and porphyritic intrusive rocks including a Nojima fault zone which involves six thin shear zones (A to F zones). These shear zones are generally surrounded by fault related rocks that are less pulverized and less altered (WPAR). The fault zone architecture is clarified as follows: (1) The total thickness of the Nojima fault zone at a depth of 1,140m is close to, but thicker than Ca. 70m. (2) All shear zones were evolved from the WPAR, indicating that pulverization and alteration of recent activity were more diffused at the initial stage of faulting, becoming gradually localized to individual shear zones. (3) Centralized layers of the shear zones contain ultracataclesite, and the D shear zone contains pseudotachylite, indicating that shear zones A to F can be regarded as a high velocity frictional zone, centralized by D zone. (4) The hanging wall and footwall of each shear zone typically shows explosion brecciation texture with carbonate and zeolite matrices, respectively, which are also regarded as dilatant co-seismic shear zones. It is possible that these zones function as a trap zone for fluid or gas during post-/interseismic periods. (5) The thick foliated clay gouge zone, which is one of the typical fault rocks in a shallow fault zone, was not detected at the 1,140m fault zone in the NIED core.

Key words : Hyogo-ken Nanbu earthquake, Nojima fault, Fault rock distribution, Microstructure, Deformation, Alteration

1. Introduction

At 5: 46 AM, on the January 17, 1995, an M=7.2 earthquake struck the southern part of Kobe city and the northwestern part of Awaji island (Hyogo-ken Nanbu earthquake). The epicenter was located at the Akashi straight and the focal depth was reported to be 14km. Surface rupture appeared more than 10 km long along the preexisting NE-SW striking Nojima fault (Awata *et al.*, 1996). Maximum displacement of surface rupture was observed at Nojima-Hirabayashi located at the northern part as 180cm right lateral and 130cm reverse components (Nakata *et al.*, 1995 ; Awata *et al.*, 1996). In 1995, the National Research Institute for Earth Science and Disaster Prevention

(NIED) began a drilling project to explore the natural state of the fault zone just after the big earthquake at Nojima Hirabayashi, and successfully penetrated the fault zone recovering the drill core of some 800m in length (1,000 to 1,800m depths) containing almost complete fault rocks from across the fault zones. The drill core is referred to as NIED core in this paper.

Fault rock distribution is one of the most important issues in understanding the dynamics of the fault zone during seismic cycles (Tanaka and Itaya, 1998). However, previous studies of the natural fault rocks in a brittle regime, from the seismogenic depth to the surface have been limited for the following two reasons, (1) processing the brittle fault rocks can be problematic since they are generally very soft and fragile, and (2) outcrop observation is limited because they are easily eroded and if present, they are usually modified mechanically and chemically by weathering in a surface condition. The NIED core contains not only fault rocks that have experienced a big earthquake but also a perfect succession from host rock to fault rocks all of which have never been weathered by surface conditions. The Cajon Pass Project is well known as a fault related drilling project (Zoback *et al*., 1988). The main purpose of this project was to investigate the geothermal anomaly along the San Andreas Fault, and drilling was performed about 4km northeast of the San Andreas Fault trace (Zoback and Lachenbruch, 1992). Therefore, detailed geological examinations of the NIED core are worthwhile for a better understanding of the fault zone architecture at shallow depths of the granitic crust. In the first instance, we have attempted to conduct a detailed analysis of fault rock distribution, and of the characterization of deformation/alteration microscopic textures.

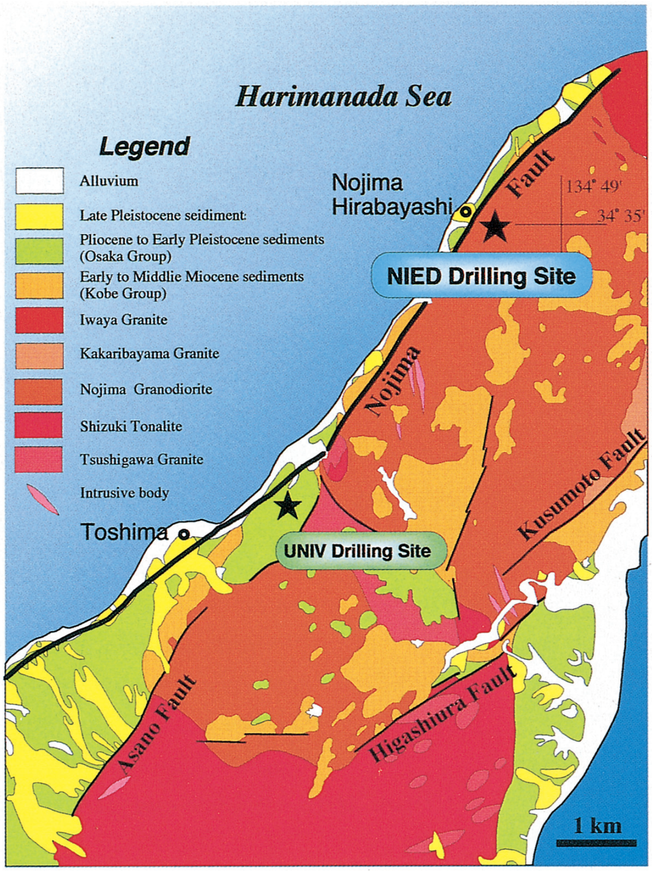

Fig. 1 Geological map around the northwestern part of Awaji Island. The NIED drilling site is located at Nojima Hirabayashi, along the northern part of Nojima fault. The drilling site of the University group is also shown on this map.

3. Outline of geology along the Nojima surface rupture and drill core

The Nojima fault is an 8km long right-lateral active fault with a minor reverse component (The research group for active faults of Japan, 1991). This fault runs along the northwestern margin of Awaji Island (Fig. 1), trending northeast and dipping southeastwards at a high angle (Mizuno *et al*., 1990). The fault juxtaposes Cretaceous granitic rocks (Nojima Granodiorite, 66 to 88 Ma ; Takahashi, 1992) partly overlain by Neogene and Quaternary sediments on the southeastern side with Neogene and Quaternary sediments on the northwestern side. The sediments on both sides belong to the middle Miocene Kobe Group and Plio-Pleistocene Osaka Group. These groups are composed mainly of sand and gravel beds intercalated with thin layers of mud (Mizuno *et al*., 1990).

The surface rupture was basically generated along the Nojima fault but extended farther southwest. The total length was estimated as 10km (Awata *et al*., 1996) to 18km (Lin and Uda, 1996). The southwestern part of the surface rupture deviated from the Nojima fault to the west and extended into Neogene sediments (Awata *et al*., 1996). The NIED drilling site was located about 300m southeast of the surface rupture of the Nojima fault near Nojima-Hirabayashi (Fig.1). Drilling was performed down to a depth of 1,822m along the direction of the drilling, with an average inclination of about 88 degrees to the northwest. It succeeded in penetrating and recovering the drill core containing the surface of the Nojima fault at drilling depths of 1,140m, 1,300m and 1,750m, respectively (see Ikeda *et al*., 2001). The dip of the Nojima fault is inferred to be Ca. 60°degrees at 1,140m depth from a spatial relationship among the outcrop of surface rupture, the depth of the fault surface in the GSJ drilling hole and the 1,140m fault surface of the

NIED drill hole and the dip of the fault surface in the drill core. The 1,140m fault zone of the NIED core mainly consists of Nojima granodiorite accompanied by minor porphyry intrusions. The fault rocks are distributed at depths extending from about 1,000 to 1,200m, and detailed examinations of fault rock distribution were performed at depths ranging from 1,054.00 to 1,189.55m, as described below. Several shear zones exist in a fault zone and each shear zone is relatively narrow and surrounded by fault related rocks that are less deformed and altered, and that are distributed over a wide area. This type of fault rock is referred to as weakly-pulverized and altered rock (WPAR) in this paper (Tanaka *et al.*, 1999).

3. Fault rock distribution along the 1,140m fault zone of the NIED core

3.1 Analytical methods

Repeated failures during core processing led us to develop the method outlined in Tanaka *et al.*, (2000). The method was applied to depths extending from 1,054.00m to 1,189.55m, where most of the core was composed of soft and fragile fault rocks.

Basically, each core piece was carved into three parts. Figure 2 shows the method of carving the core pieces into AH (Archive Half) and WH (Working Half) and further carving AH into AA (for Analyzing) and AS (Slab for preservation). After carving, the carved surface was fixed again using resin. AA was

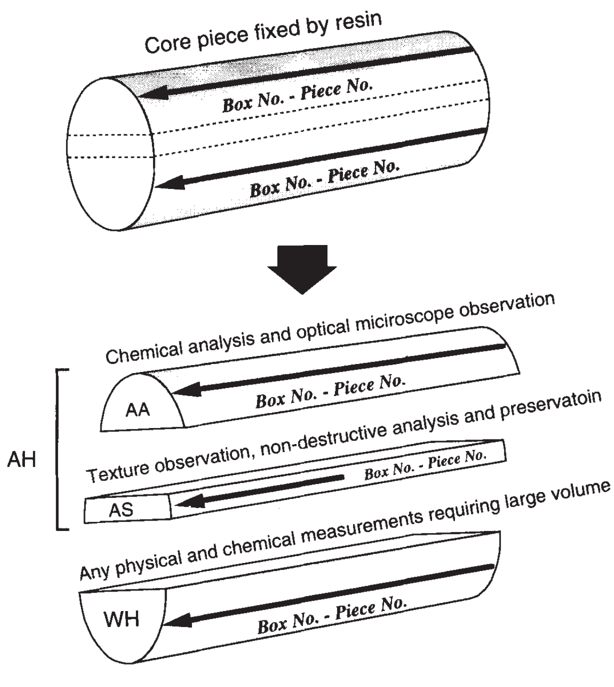

Fig. 2 The method of carving a core piece into three slabs, AA, AS, and WH. See text for detailed explanation.

utilized mainly for chemical composition and crystal structure analysis, AS for texture observations and non-destructive measurements/analysis (such as color analysis) and long term preservation after the surfaces had been polished, and WH for various kinds of measurements/observations and analysis requiring large volumes of the core.

In order to understand the whole trend of fault rock distribution in the NIED core, the surfaces of the entire drill core (1,054.00to 1,189.55m) were first observed visually and a rough fault rock distribution map was prepared. After completion of core processing, fault rock distribution was re-examined via an observation of some 1,300 pieces of the polished slabs (AS). Then, 134 thin sections were prepared throughout the core for observation of deformation/alteration microstructures. The results of the detailed description are shown in the Appendix. The rock types in the drill core were categorized into the following six types: (1) granodiorite (host rock), (2) altered porphyry intrusive rocks, (3) weakly pulverized and altered fault-related rocks (WPAR), (4) fault breccia, (5) ultracataclasite, and (6) pseudotachylite. Categories (3) to (6) correspond to the fault rock classification of Higgins (1971) and Sibson (1977) that was partly modified by Chester *et al.* (1993). The original fault rock distribution map was revised to create a precise fault rock distribution map.

3.2 Petrological characteristics of host and fault rocks from the NIED drill hole

3.2.1 Granodiorite (host rock)

The occurrence and texture of Nojima granodiorite was in detail described by Mizuno *et al.* (1990). The mesoscopic textural characteristics are as follows (Fig. 3a). Short, column-shaped hornblende crystals and thin crystals of biotite are scattered in larger quartz and feldspar crystals. Feldspars are milky white in color and quartz is relatively clear. Xenoliths, several centimeters in diameter, are occasionally included. The xenoliths have a relatively dark color, possibly due to a greater abundance of mafic minerals. Biotite K-Ar ages were reported to be 81 Ma for this rock (Takahashi, 1992). In the drilled core, although some feldspar grains had altered to become an orange color, few other alteration or deformation features were observed on the polished surfaces.

Under the microscope, the host rock shows some intercrystalline cracks containing carbonate and zeolite minerals, although their density is quite low and they are usually very narrow (Fig. 4a). Coexisting euhedral zeolite and carbonate minerals are occasionally observed in these veins. Rare micro shear

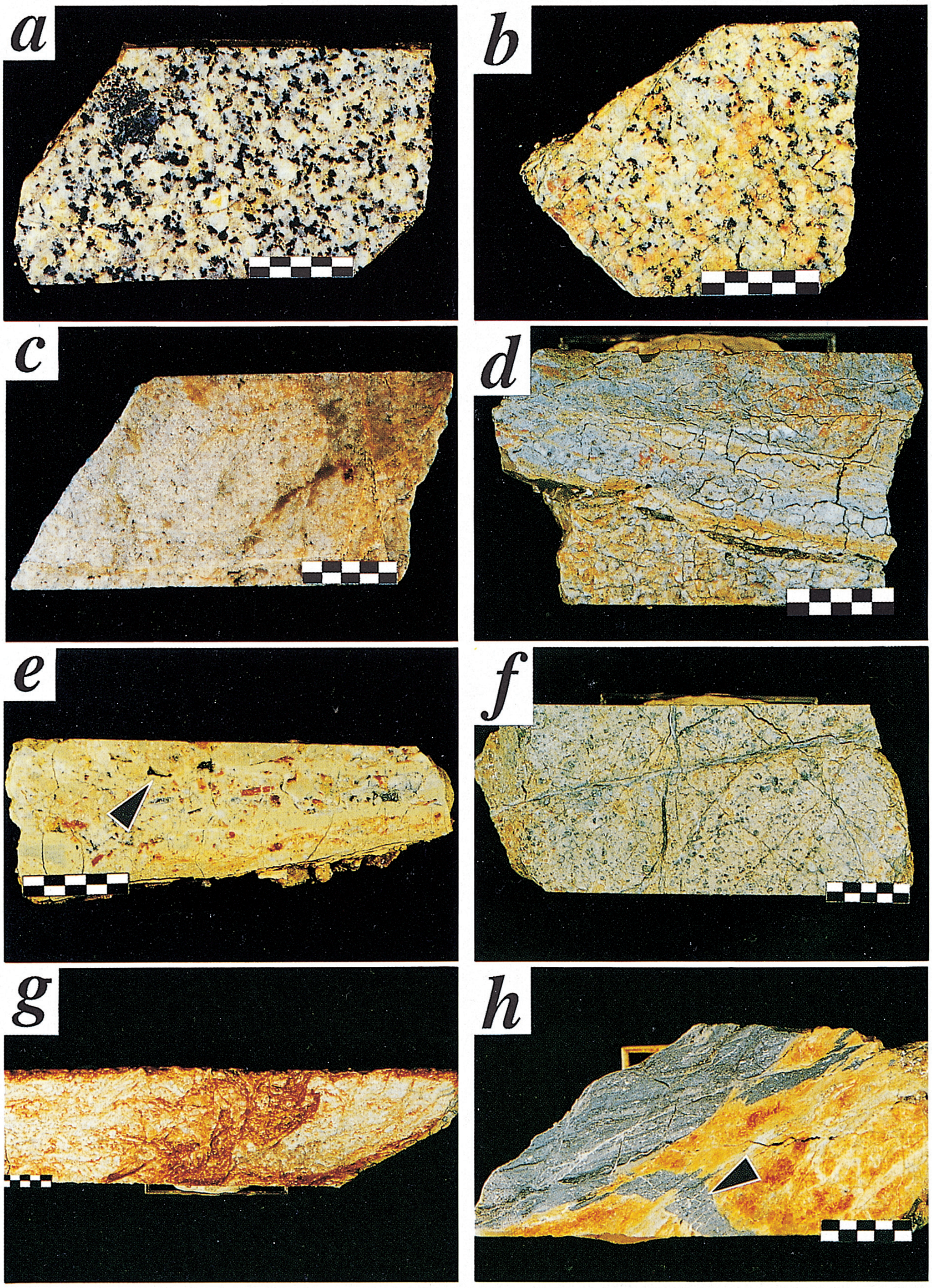

Fig. 3 Photographs showing mesoscopic textures observed on the polished surfaces of AS of each type of host and fault rocks. Bar scale : 1 cm for a couple of thick white and black bars. a, Granodiorite (host rock ; 54-32 : 1,178.26 to 1,178.35m depth) showing a "fresh" ocurrence in the 1,140 m depth fault zone. b, Weakly pulverized and altered fault-related rock (WPAR ; 39-18 : 1,104.90 to 1,104.99m). Typical occurrence of the WPAR with carbonate alteration. c, Typical occurrence of the WPAR with zeolite alteration (46-25 : 1,145.75 to 1,145.83m). d, Ultracataclasite (44-26-1 : 1,135.12 to 1,135.25m). e, Ultracataclasite (39-13 : 1,103.90 to 1,104.00m). Hydraulic brecciation texture with carbonate matrix. Note the visible pores (black arrow) present in the matrix. f, Porphyry intrusive rock (44-11-2 : 1,133.00 to 1,133.24m). g, Foliated ultracataclasite (45-25-2 : 1,140.72 to 1,140.96m). h, Pseudotachylite (45-24-1 : 1,140.57 to 1,140.66m). An arrow indicates an injection vein of pseudotachylite into the adjacent ultracataclasite layer.

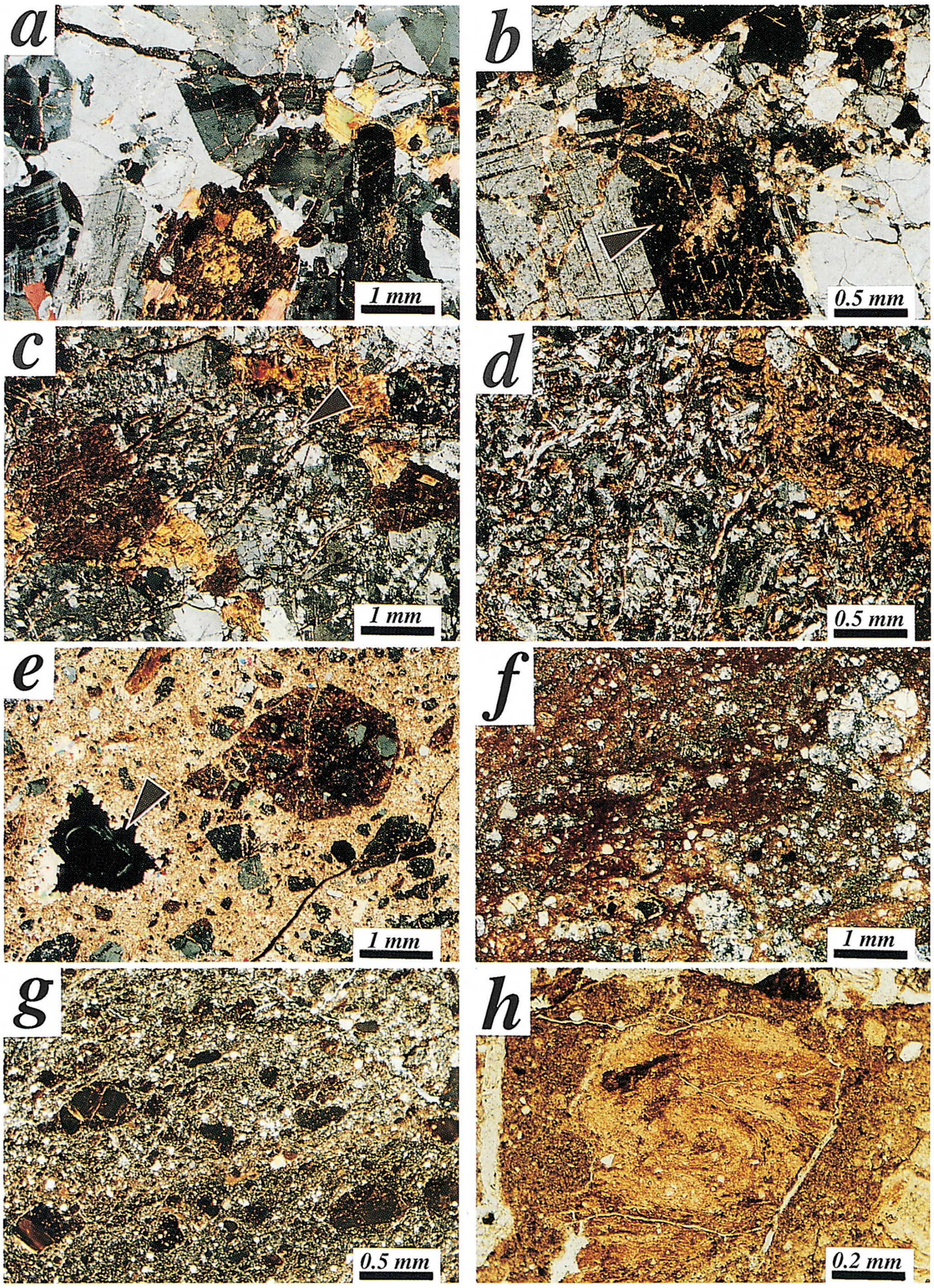

Fig. 4 Photographs showing microscopic textures observed in the thin sections of each type of host and fault rocks. a, Granodiorite (54-32 : 1,178.26 to 1,178.35m depth). Hornblende crystal (bottom center of the photograph) is partly replaced by mafic carbonate minerals and biotite. b, WPAR with carbonate alteration (42-4-1 : 1,122.29 to 1,122.43m). Note that center portion of plagioclase is partly replaced by carbonates (black arrow). c, WPAR with zeolite alteration (39-18 : 1,104.90 to 1,104.99m). Note that plagioclase is mostly replaced by zeolites (black arrow). d, Fault breccia originated from porphyry intrusive rock. Small, lath shape crystals of plagioclase remain in the sheared matrix (43-16 : 1,128.32 to 1,128.37m). e, Ultracataclasite showing hydraulic brecciation texture with carbonate matrix (39-13 : 1,103.90 to 1,104.00m). Larger crystals of calcite surround a pore, indicating that CO_2 rich fluid was filled in the pore. f, Foliated ultracataclasite with precipitation of iron hydroxide minerals (45-25-2 : 1,140.72 to 1,140.96m). g, Dark, opaque pseudotachylite grains involved in the matrix of ultracataclasite (45-24-1 : 1,140.57 to 1,140.66m). This type of fault rocks is referred to as pseudotachylite in this paper. h, A pseudotachylite clast in a vein filled with crushed, ultrafine matrial within ultracataclasite (45-19B : 1,140.03 to 1,140.16m). A spiral texture, presumably formed by turbulent flow, is preserved in the clast.

zones contain a matrix of crushed grains of the host granodiorite and carbonate micro grains and clasts of quartz, feldspars, zeolites and carbonate minerals. Wavy and blocky extinction and healed intra-grain cracks are commonly observed in quartz grains. Feldspar grains are less deformed than quartz, but occasionally weak wavy extinction of the feldspars can be observed. However, core portions of plagioclase crystals are commonly replaced by micro grains of carbonate, zeolite and sericite. Some biotite grains are partly altered to chlorite. Carbonate minerals occasionally occur as microlenses along biotite cleavages. Kink bands are well developed in some grains of biotite at large angles to their cleavages. Hornblendes are partly altered to carbonate minerals and biotite along their cleavages (Fig. 4a).

3.2.2 Altered porphyry intrusive rocks

Minor porphyry intrusive rocks were observed close to the center zone of the fault (Fig. 5). They are more or less altered and deformed. Phenocrysts varying in color from milky white to light brown are scattered in light brown colored groundmass. Grayish white veins are apparent in the heavily altered part (Fig. 3f). Porphyritic rocks are altered in a similar manner to the fault rocks of granitic origin indicating that porphyry had intruded prior to the recent activity of the Nojima fault.

Under the microscope, the groundmass is composed of plagioclase laths, quartz, biotite and mafic carbonate (Fig. 4d). Phenocrysts are dominated by plagioclase accompanied by quartz, biotite and relict crystals of hornblende. The plagioclase phenocrysts are commonly replaced by fine-grained carbonate and zeolite minerals especially in the heavily altered portion. Within the most heavily altered part, the groundmass of the porphyry has commonly altered to become cryptocrystalline materials (Fig. 4d). Few mafic minerals are preserved in these porphyritic rocks. All of these textures are commonly cut by carbonate and zeolite veins.

3.2.3 Weakly pulverized and altered fault rocks (WPAR)

The WPAR shows varying degrees of pulverization and alteration. Thus, we tentatively subdivided the WPAR based on the qualitative measure of degrees of pulverization and alteration apparent at the mesoscopic scale (Table 1). General mesoscopic descriptions of WPAR are as follows. Host rock texture is disturbed and mafic minerals are generally reduced both in size and amount due to pulverization and alteration (Fig. 3b, c). The mafic minerals are generally replaced by grayish green to grayish brown colored minerals. The cores of feldspar grains are altered and generally change color becoming grayish white or light orange. The density of the shear surfaces is low, and the shears are generally filled with grayish white, brown and greenish gray materials. The disappearance of mafic minerals and alteration of feldspar grains are common along these shear surfaces.

Intragranular cracks are prominent in quartz grains and are commonly filled with carbonate (calcite and mafic carbonates) and zeolite (laumontite and stilbite) minerals (Fig. 4b, c). Intragranular cracks are less common in feldspar grains, but the filling materials are similar to those in quartz. Intergranular cracks are also prominent features. They are filled with the

Table 1 Criteria for qualitative, visual classification of the WPAR. "Density of shear surfaces" is defined as the area ratio occupied by shear surfaces to the area of the core slab (AS in Fig. 2), and "Contents of residual mafic minerals" is defined as the ratio of mafic mineral contents of the sample to that of the fresh host rock sample.

Pulverization Index (PI)	Density of shear surfaces	Characteristics of cracks and shear surfaces
0	< 10%	healed cracks
1	< 30%	carbonate and zeolite veins
2	< 50%	carbonate, zeolite and clay veins, and/or shear surfaces containing crushed host rock minerals

Alteration Index (AI)	Contents of residual mafic minerals	Alteration of feldspars	Characteristics of secondary minerals
0	> 70%	-	-
1	> 20%	change in color into light gray, light brown and light orange	Replacement of mafic minerals (spot distribution)
2	> 5%	change in color as same as above + reduction in contents	abundant veins

same minerals as the intragranular cracks, but contain relatively large, euhedral carbonate and zeolite crystals. Micro shear surfaces are abundant and commonly contain clasts of crushed igneous, carbonate and zeolite minerals and a matrix of fine grained quartz, feldspar, carbonate, zeolite and iron hydroxide minerals. They commonly show a random fabric texture. The cores of many feldspar grains are replaced by fine-grained mafic carbonate and zeolite minerals (Fig. 4b, c). Lath shaped crystals (possibly stilpnomelane) occasionally overprint feldspars. A comparison of the alteration of feldspar grains on the polished surfaces with those in thin sections clarifies the fact that the brown or orange colored feldspar on the polished surfaces corresponds to replacement by mafic carbonate minerals and grayish white colored feldspar corresponds to replacement by zeolite minerals. Biotite grains are less abundant and smaller in size than those in the host rocks, mainly due to pulverization and alteration. Mafic carbonate and/or zeolite minerals showing a spindle shape or forming irregular aggregates are deposited between the cleavages of biotite grains. Some biotite grains show complete pseudomorphic replacement by these carbonates. Other examples of deformation and alteration of biotite include (1) kink bands which bend the intra-cleavage carbonate and zeolite minerals and (2) exfoliation brecciation along cleavages to fine grain size, which are commonly incorporated into shear surfaces and cracks. Hornblende crystals also show complete pseudomorphic replacement by biotite and/or cryptocrystalline dark materials (possibly mafic carbonate). These characteristics of pulverization and alteration, including the density of intra-and inter-granular cracks, micro-shear zones, degree of alteration of feldsper grains and mafic minerals become more intense with decreasing distance from the core part of each shear zone (Fig. 5).

3.2.4 Fault breccia

Feldspar grains generally change in color to light brown or light orange and are greatly reduced in abundance. Few mafic minerals are observed in the texture. Anastomosing development of micro shear zones, over 5mm thick, are commonly observed. They contain crushed fragments of host rock minerals surrounded by a matrix of brown-colored alteration products and/or ultrafine crystals of zeolite. The mean size of the clasts is 3mm, and the maximum is more than 50mm. Some clasts are rounded in shape, possibly due to wear and/or dissolution. The texture of the host rock or WPAR is occasionally preserved in the larger clasts. The fault breccia basically shows a random fabric, but a mesoscopic foliated texture is observed in which the fault breccia adjoins other types of fault rock, such as ultracataclasite or WPAR. Fault breccia is more intensely pulverized and altered with decreasing distance to the ultracataclasite zone.

The texture of the host rock can no be longer observed under the microscope, and the typical texture is one in which larger clasts are surrounded by a finer-grained matrix. The matrix is composed of crushed crystals of quartz and feldspars, mafic carbonate, iron hydroxide, and zeolite minerals. Clasts include quartz, healed aggregates of quartz and feldspars, and carbonate and zeolite minerals. Feldspar grains are heavily altered to carbonate and/or zeolite minerals. The biotite grains are greatly reduced in size and abundance due to comminution and alteration. Hornblendes and their pseudomorphic crystals are no longer observed. Foliation is recognized where iron hydroxide minerals are concentrated, although random fabric is dominant texture. The foliation is cut by veins containing iron hydroxide and mafic carbonate minerals.

3.2.5 Ultracataclasite

The general characteristics of ultracataclasite are well described by Chester and Logan (1986), and Chester *et al.* (1993). The texture of the host rock and most of the minerals derived from the host rock derived are obliterated except those in relatively larger clasts. Instead, ultracataclasite is composed of very fine-grained materials showing various colors such as light grayish brown, light brown and light gray (for example, Fig. 3d, e, g). Small amounts of fine-grained and rounded clasts are scattered in the variably colored matrix. The ultracataclasite is gradually developed by overprinting the fault breccia. However, in some cases, direct contact with the WPAR or fault breccia bounded by shear surfaces is observed. Foliations are commonly recognized by the color banding of these materials (Fig. 3d, g).

The ultracataclasite shows typical "clasts supported by matrix", random fabric texture (Fig. 4e, f). The matrix is composed of submicron-sized crystals of quartz, zeolites, carbonates, iron hydroxides, and minor quantities of clay minerals. The clasts are composed of crushed quartz, aggregates preserving the texture of hydraulic brecciation, carbonate minerals and zeolites. The clasts are finer and more rounded in shape than those in fault breccia. Most of the feldspars are replaced by carbonate and/or zeolite minerals. Mafic minerals are no longer observed even under high magnifications. Foliations are developed where iron hydroxide minerals are precipitated in micro shear zones, resulting in the formation of color banding in the ultracataclasite. These textures indicate that micro foliations are formed at the same time or after the precipitation of the iron hydroxide minerals. These textures are further overprinted by a hydraulic brecciation texture in some places (Fig. 4e), especially at the margins of the ultracataclasite zone. The matrix of this breccia is composed of fine-grained carbonate minerals and the clasts are composed of brecciated grains of ultracataclasite itself (Fig. 4e).

3.2.6 Pseudotachylite

Pseudotachylite is found as thin gray colored layers and interspersed with ultracataclasites at a depth of 1,140m in the Nojima fault zone (Fig. 3h). Pseudotachylite, which is referred to here, is tentatively categorized on the basis of the meso-and microscopic characteristics. Few fragments are observed in the pseudotachylite at the mesoscopic scale ; thin, dark gray colored materials are intercalated. Foliations are recognized by dark gray/gray color banding and the parallel arrangement of micro fragments. An injection structure of pseudotachylite into ultracataclasite layer is clearly observed (Fig. 3h). The injection structure and the foliations in the pseudotachylite are cut at a low angle by the surface of the boundary shear between the ultracataclasite and the pseudotachylite (Fig. 3h). The foliation developed in the ultracataclasite is also cut by the surfaces of the boundary shear. These observations indicate that the pseudotachylite was generated prior to the ultracataclasite and the newest structure is the boundary shear surface.

The fundamental texture is "clasts supported by matrix" at the microscopic scale (Fig. 4g). The matrix is predominantly composed of cryptocrystalline materials, with very fine-grained quartz and minor quantities of very fine grained carbonates scattered through it. The pseudotachylite does not contain iron hydroxide minerals, which are concentrated in the ultracataclasite. One of the most prominent features of the pseudotachylite in the NIED core is that fragments of pseudotachylite are scattered as clasts or thin layers in the ultrafine grained matrix (Fig. 4g). Wavy foliations are occasionally preserved in these clasts. Spiral / vortex texture is preserved in some of these grains (Fig. 4h). The whole texture of the pseudotachylite is cut by thin and anastomosing shear surfaces containing clay minerals. These facts also indicate the pseudotachylite is older than ultracataclasite.

4. Characterization of alteration of the fault rocks

Most of the alterations to host and fault rocks are basically categorized into the following three types based on the microtextural observations (see Appendix for reference). (1) Carbonate type (C type): Typical meso-/microscopic textures are shown in Fig. 3b and Fig. 4b. The crack fillings are dominated by carbonate minerals. Further, plagioclase crystals are more or less replaced by carbonates. Microspherules of mafic carbonate are commonly observed between the cleavages of biotite. (2) Zeolite type (Z type): Typical textures are shown in Fig. 3c and Fig. 4c. The crack fillings are dominated by zeolite minerals. Plagioclase crystals are replaced by zeolite. Microlenses of zeolite are observed between cleavages of biotite as well as carbonate spherules. Fault rocks with Z type alteration are generally overprinted by C type alteration, which means coexisting types of alteration are commonly observed. This type of alteration is referred to as Carbonate/Zeoite type (C/Z type). (3) Mafic Carbonate/Iron Hydroxide type (MC/IH type): Typical textures are shown in Fig. 3g and Fig. 4e, f. This type of alteration is deeply involved with fault breccia and ultracataclasite. The ultrafine grain size of the mafic carbonate/iron hydroxide minerals serves as the matrix of these fault rocks. Clasts in those fault rocks commonly preserve textures of C, Z and C/Z types. While clasts of ultracataclasite are preserved in a hydraulic breciatiation texture with carbonate matrix (Fig. 3e, Fig. 4e), indicating repeated process of brecciation coupled with C and MC/IH types alteration. It should be noted that flow textures are prominent where iron hydroxide minerals are precipitated.

5. Discussion

5.1 Distribution and structural evolution of each shear zone in the Nojima fault

Detailed fault rock distribution is shown in Fig. 5. At the mesoscopic scale of observation, fault related comminution and alteration gradually increase in the NIED core from the top and bottom to the core zone of the Nojima fault (around 1,140m) (Fig. 5). Fresh host rocks are not present even in the shallower and deeper parts in the extent except the depth range of from 1,184.70m to 1,185.27m. Thus, the entire extent from the depth of 1,054.00m to 1,189.55m is treated as the Nojima fault zone in this paper. The fault zone may extend to shallower and greater depths, since pulverization and alteration are observed even at the top and bottom of the analyzed extent. In the Nojima

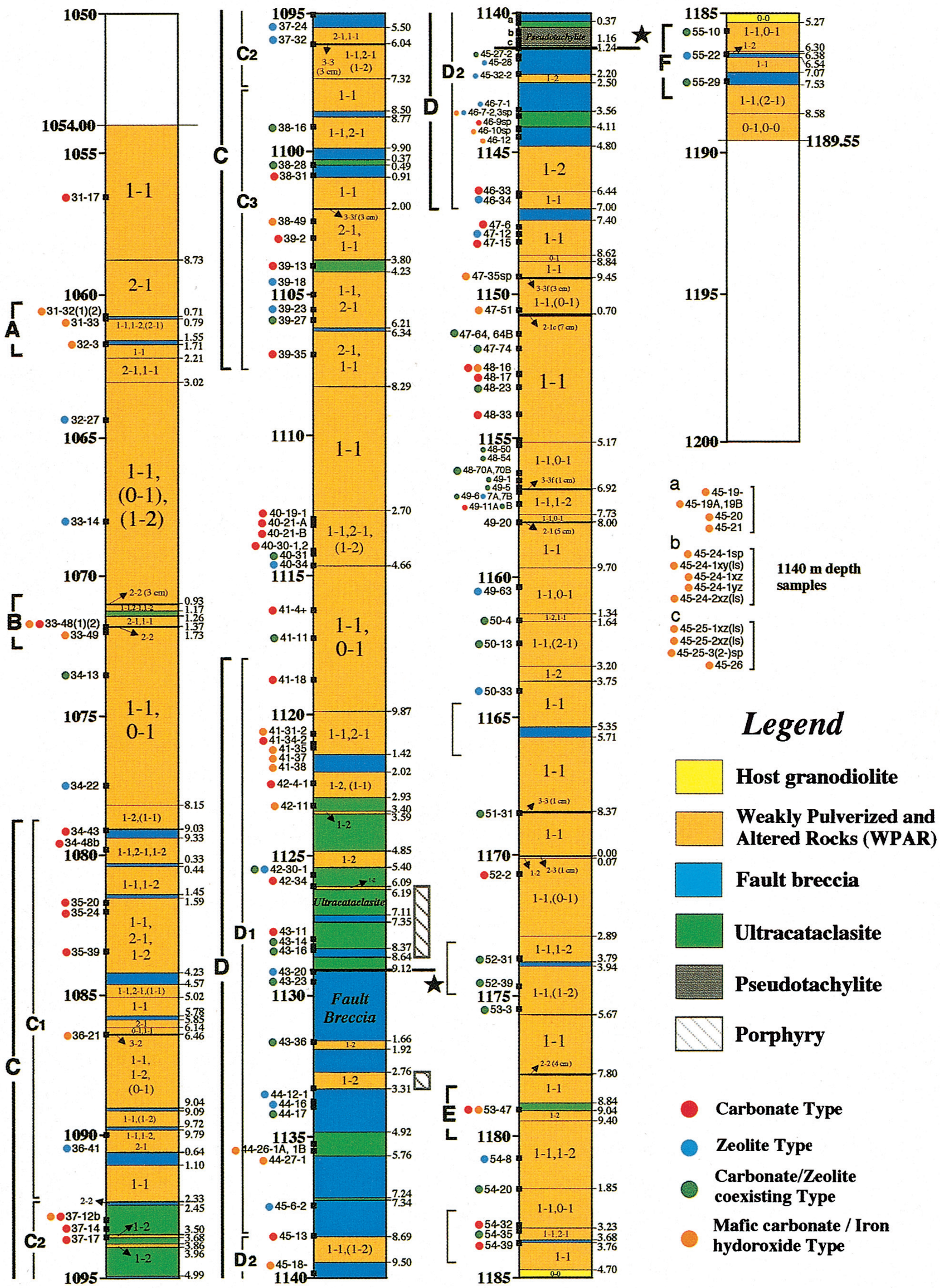

Fig. 5 Detailed fault rock distribution map for the depth range of from 1,054.00 to 1,189.55m in the NIED core. The WPAR classification is indicated by numbers, e.g. 1-1 represents PI-AI, which is based on the criteria shown in Table 1. More than two classifications in a range indicate that the first one is predominant, and classifications noted in parenthesizes indicate the rare presence of that kind of WPAR. The depths are indicated at both right and left sides of the columns. The left ones show depths at 5m intervals and the right ones show depths up to 1 cm order with an accuracy of ±5cm. The six major shear zones are indicated in gray parenthesizes with bold letters, and minor ones are just shown using gray parenthesizes. Samples and their depth ranges for microstructural examinations are indicated by small black rectangles with sample numbers. See text for further explanations.

fault zone, several shear zones, showing similar characteristics, are present.

Analysis of fault rock distribution clarifies the fact that the Nojima fault zone contains six major shear zones, from shallower to deeper levels, these are the A to F zones. Each shear zone is surrounded by the WPAR. Among these, the C and D zones are the candidates for the core zone of the Nojima fault for the following reasons. (1) The C and D zones are relatively thick as a whole, and have sub-shear zones (C1 to C3 and D1 to D2). (2) The C and D zones contain fault breccia, relatively thick ultracataclasite, and the D zone has a pseudotachylite layer. (3) Density, porosity, elastic wave velocity and other physical logging data show a distinct change or anomalies especially in these zones. The degree of change in these data is greater in the D zone than in the C zone (Ikeda *et al.*, 2001, Omura *et al.*, 2001), indicating that the D zone is more likely to have been activated during the 1995 earthquake. These results suggest that the C and D zones contain localized fault surfaces formed by co-seismic events and that the D zone might have been formed at more recent, including current, seismic events, while the C zone is consolidated, and thus is the older shear zone. Therefore, we offer a tentative definition of the Nojima fault surface as the fault surface that appeared at the bottom of the D2 subzone, the boundary between the ultracataclasite and fault breccia (1,141.24m depth). Results of mineral assemblage analysis (Matsuda *et al.*, 2001) indicate that the fault surface is a boundary between laumontile (hanging wall) and laumontile + stillbite (footwall) assemblages. This indicates that the fault surface at this depth has experienced large displacements with reverse components, since higher temperature assemblage appears at the shallower depths. Meanwhile, chemical composition data (Matsuda *et al.*, 2001) shows anomalously high concentrations of HFSE (High Field Strength Elements) around the depth of 1,125m, which corresponds to the D1 subzone. Concentration of HFSE is considered to be one of the typical characteristics of the frictional fault zone (Goddard and Evans, 1995 ; Evans and Chester, 1995). Thus, another candidate of the main fault surface of the 1995 event is at the boundary between the ultracataclasite and fault breccia in the center of the D1 subzone (1,129.12m depth, Fig .5). In addition, it should also be noted that the A or B shear zone might have been activated during the 1995 earthquake, based on the distinct anomalies of geophysical logging data (Omura *et al.*, 2001).

The history of the evolution of the Nojima fault zone in the NIED core, clarified by meso-and microscopic observations is as follows. Deformation and alteration of the WPAR overprint porphyry, suggests that the WPAR was formed after intrusion of porphyry. The WPAR is overprinted by fault breccia, which is further overprinted by ultracataclasite indicating the formation sequence of these fault rocks. A crosscutting relationship between micro shear surfaces and foliations both in the ultracataclasite and pseudotachylite shows that the pseudotachylite was formed after the ultracataclasite. The presence of an injection structure of the pseudotachylite into the ultracataclasite also supports this observation. From the above mentioned observations and considerations, it is possible to assert that fault rocks in the NIED 1,140m fault zone were basically formed in the following order (1) Host rocks, (2) Porphyry intrusive rock, (3) WPAR, (4) Fault breccia, (5) Ultracataclasite and (6) Pseudotachylite. This result suggests that every shear zone, including zones A to F were evolved from WPAR overprinting host rocks. Although there are several ultracataclasite zones present in the C and D zones, a lack of clear evidence of overprinting relationships among them precludes further interpretation of their formation sequence. However, it should be pointed out that the juxtaposition of several ultracataclasite layers and the absence of a clay gouge layer is one of the prominent features in the 1,140m fault zone of the NIED core, which contrasts with the characteristics observed at the GSJ Hirabayashi core (Tanaka *et al.*, 2000 ; Fujimoto *et al.*, in press ; Ohtani *et al.*, 2000).

Three additional thin shear zones containing fault breccia are also recognized in the Nojima fault zone (Fig.5). Although they may be regarded as nucleations of shear localization, further examinations are necessary to clarify this issue.

5.2 Characterization of each shear zone and the WPAR in the Nojima fault zone

Each shear zone shown in Fig. 5 is basically discriminated by the mode of fault rock distribution and by the deformation/alteration modes of fault rocks. Generally, each shear zone is centralized by the fault rocks that have experienced the heaviest pulverization and alteration, such as ultracataclasite, fault breccia, and pseudotachylite with MC/IH type alteration. Fault rocks in the hanging wall are characterized by C and C/Z type alteration, while those in the footwall are by Z type alteration. These contracting characteristics help distinguish between individual shear zones (Fig. 5). This trend is also common in the GSJ core (Tanaka *et al.*, 2000). Among the six major shear zones distinguished in the NIED core, the A, B, E and F zones are less well characterized mainly due to of the narrowness of these zones and the absence of microstructural data. Thus, we have omitted these zones from the present discussion in order to concentrate on clarifying the mechanisms of faulting during seismic cycles at shallow depths.

The C_2 subzone in the C zone and both subzones in the D zone (D_1 and D_2) have thick ultracataclasite layers. We will focus on the deformation and alteration of these three subzones. Microstructural observation of the fault rocks in the center zones of each subzone reveals that (1) the most dominant texture is random fabric and foliations are rarely observed, except in thin layers filled with MC/IH minerals developed in fault breccia and ultracataclasite, and (2) the wavy/spiral foliation, which is similar to the flow lines of turbulence are observed within dark brown clasts in the pseudotachylite layer in the D_2 zone (Fig. 4g, h). The former suggests that minor flow deformation likely occurred after the inflow of Fe^{3+} rich fluids into the core (part) of the shear zone. The latter suggests that fluidization or melting occurred during high velocity, co-seismic movement within the D^2 zone as proposed by Ohtsuki (2000). In the GSJ core, dark brown materials contained in the pseudotachylite are inferred to be graphite by chemical analysis (Tanaka *et al.*, 2000). If this is the case, the only possible origin of the graphite is the carbonate minerals or CO_2 gas, suggesting that deoxidation occurred in this pseudotachylite, possibly caused by frictional heating under the low oxygen conditions that are present during the co-seismic period (Tanaka *et al.*, 2000). From these considerations, it can be assumed that the D_2 shear zone was formed by localized, high-velocity frictional motion of the fault.

C type alteration, commonly observed at the hanging wall of each shear zone could be the result of surface water, since it generally contains a large amount of CO_2 gas. Dilatancy is a necessary characteristic for the inflow of such fluids into the zone. Thus, this zone could have been formed during co-seismic periods. The characteristics of Z type alteration at the footwall of each shear zones are as follows; (1) abundant zeolite veins in the matrix of hydraulically brecciated rock, and (2) feldspar crystals being mainly altered to zeolite. Co-seismic activity of this zone is clearly evidenced by (1), which also suggests the super-hydrostatic condition of the footwall of each shear zone at the seismic faulting. The fact of (2) also implies a slower rate of fluid flow containing similar chemical composition of plagioclase. From these considerations, the footwall of each shear zone could have been a fluid-rich, co-seismic brecciation zone during seismic cycles. This fluid could be derived from a slower flow rate through the intracrystalline path in feldspars, which is then trapped in this shear zone. The fluid is possibly of deeper origin, because the relatively thick, impermeable layers of the fine grand material in the fault core (ultracataclasite and pseudotachylite) (Naka *et al.*, 1998; Lockner *et al.*, 2000) preclude the down flow of fluids of meteoric origin.

The WPAR is widely distributed, surrounding the every shear zone in the NIED core. During post- and interseismic periods they could be the conduit for fluid flow, due to the opening of cracks and dilatancy caused by seismic failure (Caine *et al.*, 1996; Seront *et al.*, 1998; Caine and Forster, 1999). This could be proved by the presence of euhedral, large grains of carbonate and zeolite filling cracks.

5.3 Mechanical roles of each shear zone during seismic cycle in the Nojima fault

Recently the concept of a shear zone architecture has undergone major revisions mainly based on microstructural observations, chemical measurements and permeability measurements (Chester and Logan, 1986; Chester *et al.*, 1993; Evans and Chester, 1995; Goddard and Evans, 1995; Caine *et al.*, 1996; Caine and Forster, 1999; Evans *et al.*, 1997; Lockner *et al.*, 2000). To date, two distinct zones have been recognized in the fault zone from these results. One is the fault core, which is characterized by relatively low shear strength and very low permeability mainly caused by very-fine grained nature of the fault rocks in this zone. Another is the damaged zone, which has a tabular form and surrounds the fault core. The damaged zone is characterized by moderate strength and moderate to high permeability (Lockner *et al.*, 2000). These two zones are further surrounded by the protolith (host rock) which shows a higher shear strength and very low permeability. The fault core - damaged zone model is quite reasonable as a means of understanding the fault zone architecture and the mechanics of the Nojima fault zone in the NIED core at a depth of 1,140m. We will attempt to construct a realistic model because we now have a detailed understanding of the fault rock distribution as a result of a vast amount of core observation of polished surfaces and microstructural observations of 134 thin sections, as described so far. Figure 6 shows a mechanism map of the fault zone of the NIED core at a depth of around 1,140m. Physical logging results, mesoscopic and microstructural observations all indicate that the

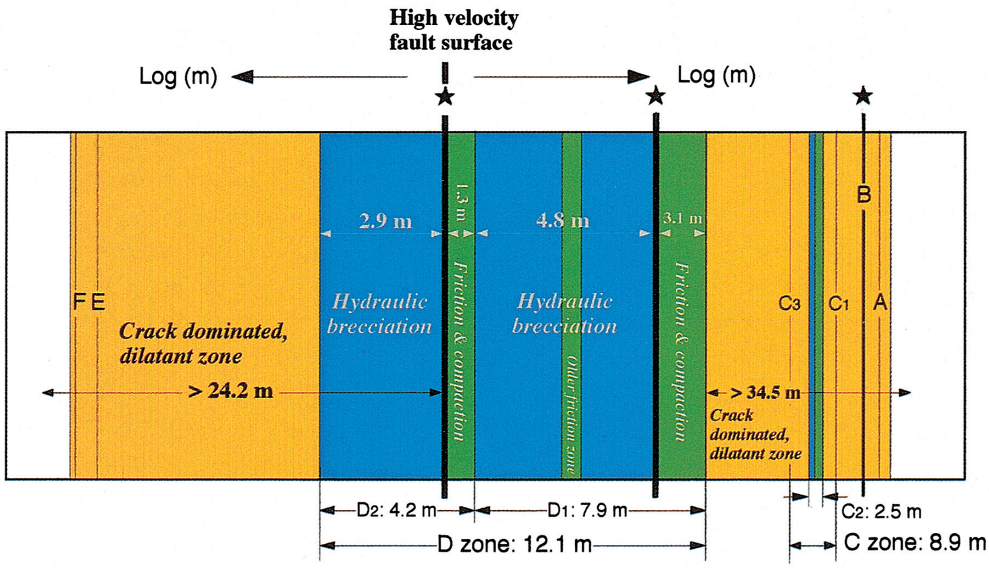

Fig. 6 Mechanism map of the Nojima fault zone interpreted from fault rock distribution and meso-/microstructural observation, showing that several, high velocity shear zones exist in a fault zone. The thickness of the fault zone is presented using the log scale. See text for detailed explanations.

centralized zone in the Nojima fault zone is the D_2 and/or D_1 shear zone. Both zones are composed of three parts, each of which played a different role during earthquakes. The hanging wall of the shear zone is characterized by dilatant, crack dominated deformation and inflow of CO_2 rich fluids which are possibly of surface water origin. This part may play the role of the trapped zone for surface fluid during an interseismic period and the hydraulic brecciation zone during a coseismic period. Microtexturral characteristics of the footwall of the shear zone are basically similar to the hanging wall. However, Z type alterations are prominent instead of C type alterations. Where minor C type alteration is observed, it overprints the Z type alteration. Thus, the footwall shear zone may be formed by one of the following two mechanisms. (1) Z type alteration occuring throughout the fault zone at older stages, and somehow being preserved in the footwall shear zone. (2) Z type alteration occuring during recent interseismic periods especially at the footwall which have played the role of hydraulic brecciation zone during coseismic periods. Although, both cases are possible, it should be pointed out that fluid flow in the hanging wall has not connected with that in the footwall shear zone, since the mode of alteration differs between the two.

The centralized layer of the shear zone is characterized by the highly fine grained nature of the fault rocks, the absence of veins filled with secondary minerals, and possible evidence of heat generation and minor flow deformation where iron hydroxide minerals are precipitated. These features suggest that the centralized layers of the shear zones could play the role of frictional, high-velocity, large displacement zone during coseismic periods. Precipitation of iron hydorxide minerals and minor flow deformation within them may represent an inflow of Fe^{3+} rich fluid during a coseismic period and post seismic creep deformation. A common characteristic of the center zone of the fault is a very fine grained nature of the matrix of fault rocks, suggesting that the core could be a fluid barrier during interseismic periods (Chester *et al*., 1993 ; Lockner *et al*., 2000). This consideration would be supported by the fact that alteration mode is different between the hanging and footwalls.

Few clay-rich shear zones were observed in the NIED core at the depth of 1,140m, which was observed in the GSJ core and which is regarded as an interseismic, creeping shear zone by Tanaka *et al*. (2000). Instead, many thin layers (<1 cm thick) showing "flow texture" filled with clay, iron hydroxide and self crushing materials are distributed throughout the fault, suggesting that the creep zone may not be localized at this depth. Dominant flow textures are observed at the 1,300m fault zone (Kobayashi *et al*., 2001), suggesting another possible explanation, that the 1,300 m fault zone could have a function of flow deformation.

6. Conclusion

We have performed fault rock distribution analysis and microstructural observations on deformation and alteration throughout the shear zone at a depth of 1,140m in the NIED core. These data lead to the following conclusions.

The whole fault zone is thicker than 67m in and contains six major shear zones which are denoted as shear zones A to F becoming gradually deeper. Every shear zone is surrounded by weakly pulverized and altered fault-related rocks (WPAR). Detailed microstructural observations have been performed for the C and D shear zones. Both shear zones have subzones (C_1 to C_3, and D_1 and D_2), which have formed during recent activities of the Nojima fault. However, the C zone was formed at an early, older stage than the D zone.

The C and D zones are located at depths of around 1,095m and 1,140m, respectively. Both zones are characterized by random fabric fault breccia, ultracataclasite and pseudotachylite. The microstructural examination clarifies that these zones are regarded as the high-velocity co-seismic zones associated with heat generation. The hanging wall and the footwall of these two zones are characterized by dominant hydraulic brecciation texture. These zones are regarded as a fluid trapped zone formed during the post-/interseismic periods and a hydraulic explosion zone formed during the coseismic periods. The fact that the mode of alteration in the hanging wall (C type) is different from that in the footwall (Z type) suggests that center zones of the fault (C, D zones) would have acted as the fluid barrier during interseismic periods. Broadly, the C and D shear zones are regarded as the co-seismic fault core, in which each part behaves differently. There is no clay rich, slow velocity creeping zone in this depth range of the NIED core. This may suggest that the creep zone is located at another depth range, or that creeping may have occurred in scattered thin shear zones. The WPAR surrounding these shear zones is characterized by numerous cracks containing carbonate and zeolite minerals. This zone is regarded as a dilatant, co-seismic zone at the marginal part of the main shear surfaces, and as a fluid conduit during post- / interseismic periods.

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Appendix Results of microtextural observations of fault rocks under the optical microscope.

Descriptions under Optical Microscope

00'10'27 ver.2.0

Type of alteration	Orientations of structure	Mode of pulverization	Description of cracks	Mode of extinction	Alteration of feldspars	Description of Kink bands
C: Carbonate Type	Direction parallel to the diameter of the core: 0°	**In the case that host framework texture is preserved**	Trans (fillings)	Wavy extinction: W-EX	Not altered: -	Predominant: Most of the grains have kink bands
Z: Zeolite type	Perpendicular (90°)	cracks	Sequence: 1,2,3,...	Blocky extinction: B-EX	Not clear: N/C	Common: Half of the grains have kink bands
C/Z: Coexisting of Carbonate and Zeolite type	High (90 - 60°)	mbsz (pulverized materials, precipitation and healing)	If seqence of deformation is not clarified	**Example:**		Present: Some grains have kink bands
MC: Mafic Carbonate Type	Moderate (60 - 30°)	**In the case of matrix+clast structure**		Quartz: W-EX, B-EX		-: None
IH: Iron hydroxide type	Low (30 - 0°)	Random fabric: / foliated		Feldspar: W-EX		
	Horizontal	matrix (minerals) + clast (minerals)				
	No preferred orientation, N/C	cracks				
		mbsz (microscopic brittle shear zone) (pulverized materials, healing minerals)				

				Description of deformation mode			Description of each mineral											Etc.
							Quartz / feldspar		Feldspar (plagioclase / orthoclase)	Biotite						Hornblende		
Thin section boxes	Depth	Thin section number	Rock type	Orientations of structure	Mode of pulverization	Inter granular cracks	Mode of extinction	Fragmentation	Alteration of feldspars (replaced)	Chloritization	Secondary minerals between cleavages (carbonate, zeolite)	Pseudomorphic replacement by carbonate	Kink band / hydration softening and bending	Exfoliation, fragmentation, and crack fillings	Decrease by alteration in amounts	degree of alteration, represented by amounts of pseudo-morphs	Decrease by alteration	
A	1056.524	31-17	**1-1: WPAR (C)**	-	Host framework texture preserved,cracks, mbsz (healed self-crushed fragments + carbonate)	Trans (carbonate), Trans (zeolite)	Quartz / feldspar : W-EX	observed in mbsz	A part of core portions are replaced by (sericite, carbonate, zeolite)	-	Carbonate (common), zeolite (common)	-	Common (kink bands)	-	-	Small numbers of pseudomorphs (mafic carbonate)	Decrease	
A	1060.709	31-32(1)	**3-1: Fault breccia (MC)**	Moderate	Random fabric: matrix (fine-grained, self-crushed fragments + fine-grained carbonate + dark brown fine-grained minerals) + clast (self-crushed fragments), mbsz (fragmented biotite)	Feldspar clasts containing carbonate, zeolite veins. No vein in the matrix.	Quartz: weak W-EX	Predominant	Most of feldspar clasts are replaced by carbonate and zeolite. Feldspar clasts surrounded by biotite grains show less alteration.	-	Carbonate (ribon shape)	Rare	Present (kink bands)	Predominant within mbsz	Decrease	Small numbers of deformed pseudomorphs	Lost	Heavily pulverized part in A shear zone.
A	1060.709	31-32(2)	**3-1: Fault breccia (MC)**	Moderate	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate + dark brown fine-grained minerals) + clast (self-crushed fragments), mbsz (fragmented biotite)	Grain cracking is predominant both in Quartz and Feldspars. No veins in the matrix.	Quartz / feldspar: weak W-EX	Predominant	Most of feldspar clasts are replaced with carbonate and zeolite.	-	Carbonate (ribon shape)	extremely rare	Present (kink bands)	Predominant along mbsz	Decrease	Small numbers of deformed psedomorphs are remaining	Lost	Biotite grains are well foliated. Flow texture of biotites present around fragmented clasts.
A	1060.788	31-33	**2-2: Fault breccia (MC)**	Moderate	Random fabric: matrix (fine-grained, self-crushed fragments + carbonate + dark brown fine-grained minerals) + clast (self-crushed fragments + carbonate), mbsz (ultra fine-grained (self-crushed fragments + carbonate))	Trans (carbonate vein)	Quartz: weak wavy + B-EX, feldspar: weak W-EX	Quartz clasts with predominant hydraulic brecciation texture (zeolite matrix).	Most of feldspar clasts are replaced by zeolite.	-	Predominant spherule carbonates	Prominent carbonate replacements	-	-	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	This sample is characterized by zeolite + mafic carbonate alteration. It may be common character in the fault rocks just beneath the Nojima shear zone.
A	1061.706	32-3	**2-2: Fault breccia (MC)**	Low	Host framework texture is barely preserved, with large numbers of cracks. Random fabric part: matrix (self-crushed fragments + fine-grained carbonate), mbsz (fine-grained self-crushed fragments + fine-grained carbonate)	Trans (carbonate)	Quartz: weak W-EX, many clasts bounded by cracks show similar orientation of extinction, feldspar: weak W-EX	Predominant, especially in mbsz	Fine grained sericite. Carbonate in some grains.	observed in some grains	Spherule mafic carbonate, ribon zeolite in some grains	Common	Present (kink bands)	Common	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	This sample is from upper part of A shear zone and beneath the fault breccia, characterized by lack of zeolite and abundant mafic carbonates.
A	1064.380	32-27	**1-1: WPAR (Z) (sample is from close to the Zeolite vein)**	High (zeolite vein)	Host framework texture, cracks (thick zeolite vein).	Trans (zeolite great), trans (carbonate)	Quartz: weak W-EX, B-EX, feldspar, weak W-EX	Minor	Fine grained sericite. Predominant Replacement by zeolite.	observed in some grains	Spherule mafic carbonate, ribon zeolite in some grains	Common	Present (kink bands)	present	Decrease	Small numbers of pseudomorphs	Lost	WPAR between A/B shear zone. As this sample is from close to thick zeolite vein, alteration is mainly affected by zeolite. It may be one of the characteristics of lower part of shear zone.
A	1068.042	33-14	**1-1: WPAR (Z) (sample is from close to the Zeolite vein)**	Perpendicular	Host framework texture, cracks.	Trans (zeolite great), trans (carbonate). Zeolite grains are sheared and brecciated with in a vein.	Quartz: weak W-EX, B-EX, feldspar, weak W-EX	Minor. Interlocking texture between quartz grains.	Fine grained sericite. Replace of zeolite is predominant.	-	Spherule mafic carbonate, ribon zeolite in some grains	Common	Present (kink bands are formed before spherule carbonates)	present	Decrease	Small numbers of pseudomorphs	Lost	WPAR between A/B shear zone. Zeolite type.
A	1071.372	33-48(1)	**1-1: WPAR (C)**	Moderate	Host framework texture is barely preserved. Cracks (carbonate + zeolite), mbsz (self-crushed fragments + zeolite + fine-grained carbonate)	Trans (carbonate + euhedral zeolite (great)), trans (zeolite).	Quartz: weak W-EX and B-EX, feldspar: weak W-EX	Minor	Fine grained sericite + carbonate. Predominant replacement of zeolite.	-	Spherule mafic carbonate, ribon zeolite in some grains	Predominant	Few kink bands. Predominant bending texture of cleavages	present	Decrease	Small numbers of pseudomorphs	Lost	Lower part of B shear zone. Carbonate dominated thin shear zone

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A	1071.372	**33-48(2)**	**1-1/3-3: WPAR (C) / Ultracataclasite (MC)**	Moderate	Random fabric: matrix in Ultracataclasite. (ultrafine-grained, healed, self-crushed fragments + fine-grained carbonates) + clast (self-crushed fragments + zeolite + carbonate). mbsz (flow texture, clasts derived from ultracataclasite + ultrafine-grained carbonate matrix)	Trans (carbonate), hydraulic brecciation texture	Quartz / feldspar: weak W-EX	Dominant	Feldspar clasts (sericite, zeolite)	-	-	-	-	-	Lost	-	Lost	Lower part of B shear zone. Carbonate dominated thin shear zone .
A	1071.480	**33-49**	**2-1: WPAR (MC) (thin ultracataclasite zone)**	High	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate + dark brown fine-grained minerals) + clast (self-crushed fragments + zeolite). mbsz (fine-grained self-crushed fragments + fine-grained carbonate + small amounts of clay (foliated))	1. trans (zeolite), 2 mbsz	Quartz / feldspar: weak W-EX + B-EX. Fine fragments show equant extinction in mbsz.	Predominant, especially in mbsz.	Feldspar clasts (zeolite, sericite, carbonate)	-	ribon mafic carbonate	Predominant	Kink bands still remains	present	Extremely decrease	Small numbers of pseudomorphs	Lost	Lower part of B shear zone. Mafic carbonate dominated thin shear zone .
A	1073.587	**34-13**	**0-1: WPAR (C/Z)**	-	Preserved host framework texture, cracks (carbonate + euhedral zeolite)	1. trans (zeolite), 2 trans (carbonate)	Quartz / feldspar: weak W-EX	-	Fine grained sericite, zeolite. Carbonate in some grains.	-	ribon, spherule zeolite + mafic carbonate	Predominant	Kink bands still remains	Rare but present	Decrease	Pseudomorphs	Lost	WPAR between B/C shear zone. Coexisting type.
A	1077.497	**34-22**	**1-1: WPAR (Z)**	High	Host framework texture is barely preserved, cracks.	1. trans (zeolite), 2. trans (carbonate), Hydraulic brecciation texture within carbonate veins	Quartz / feldspar: weak W-EX + B-EX. Many clasts bounded by cracks show similar orientation of extinction.	Predominant, into blocls bounded by carbonate veins.	Less altered, zeolite replacements in some grains	-	Spherule carbonate	Predominant	-	-	Extremely decrease	Small numbers of pseudomorphs	Lost	WPAR just above the C shear zone. Zeolite type.
A	1079.142	**34-43**	**2-2: Fault breccia (C)**	High	Random fabric: matrix (fine-grained carbonate (large amounts) + fine-grained self-crushed fragments (small amounts)) + clast (self-crushed fragments). Weak foliation.	Fine grained carbonate matrix, trans (coarse carbonate fillings) with void pores.	Clast quartz / feldspar: weak W-EX	Predominant clasts (average: 2 mm)	Some of feldspars in clasts are replaced by zeolite.	-	-	-	-	-	Lost	No pseudomorphs	Lost	Upper part of C1 shear zone. Carbonate type fault breccia.
A	1079.729	**34-48b**	**2-2: Fault breccia (C)**	Perpendicular	Random fabric: matrix (fine-grained carbonate + self-crushed fragments) + clast (zeolite vein cataclasite + self-crushed fragments). Weak foliations in carbonate matrix.	Trans (carbonate)	Clast quartz / feldspar: weak W-EX	Predominant clasts (average: 1 mm)	Some of feldspars in clasts are replaced by zeolite.	-	-	-	-	-	Lost	No pseudomorphs	Lost	Upper part of C1 shear zone. Carbonate type fault breccia.
A	1081.705	**35-20**	**2-2: Fault breccia (C)**	Perpendicular	Random fabric: matrix (fine-grained carbonate) + clast (cataclasite containing zeolite veins + self-crushed fragments).	Fine grained carbonate matrix, trans (coarse carbonate fillings) with void pores.	Clast quartz / feldspar: weak W-EX	Predominant clasts (average: 1 mm)	Decrease of feldspar clasts. Most of relict feldspars are replaced by zeolite.	-	Spherule carbonate (Only 1 grain remains)	-	-	-	Only 2 grains are remaining. Almost lost	Small numbers of deformed pseudomorphs	Lost	Middle part of C1 shear zone. Carbonate type fault breccia.
A	1082.039	**35-24**	**2-2: Fault breccia (C) (less pulverized)**	Moderate	Random fabric: matrix (fine-grained carbonate) + clast (zeolite cataclasite + self-crushed fragments)	Trans (carbonate)	Quartz / feldspar: weak W-EX + B-EX in some grains. Some clasts bounded by cracks show similar orientation of extinction.	clasts (average 5 mm to 1 cm). Grains are somewhat larger.	Most of feldspar clasts are replaced by zeolite. Zeolite is typical secondary minerals in feldspars, and few carbonate and sericite alteration can be observed.	-	Spherule carbonate	Predominant	-	Replaced carbonate spherules are released into cracks	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	Middle part of C1 shear zone. Weak carbonate type fault breccia.
A	1083.473	**35-39**	**1-2: WPAR (C)**	Perpendicular	Host framework texture is varely preserved. cracks, mbsz (> 5 mm), hydraoulic brecciation with carbonate matrix, self-crushed fragments)	Trans (carbonate), contains voids in coarser grained part	Quartz / feldspar: weak W-EX	Common in mbsz (average: 3 to 5 mm)	Replaced by Zeolites. Small amount of carbonate overprints	-	Spherule carbonate	Predominant	-	Prominent hydration softening with carbonate spherules, elongated nature along cracks	Extremely decrease	Small numbers of pseudomorphs	Lost	Middle part of C1 shear zone. Carbonate type WPAR.
A	1086.459	**36-21**	**1-1/3-2: Cataclasite (MC)**	Horizontal	Random fabric: matrix (fine-grained dark brown mineral (possibly altered products of hornblende) + fine-grained self-crushed fragments) + clast (self-crushed fragments + zeolite), mbsz (self-crushed fragments)	Only 1 trans (zeolite)	Quartz / feldspar: weak W-EX	Predominant (average: 2 to 5 mm)	Small amounts of sericite. Small amounts of carbonate overprints, dominant zeolite alteration.	-	Spherule carbonate, ribon zeolite	Common	-	Prominent hydration softening with carbonate spherules, elongated nature along cracks	Decrease	Small numbers of pseudomorphs	Lost	Lower part of C1 shear zone. Mafic carbonate type Cataclasite. Horizontal.
A	1089.793	**36-41**	**2-2: Fault breccia (Z)**	N/C	Random fabric: matrix (zeolite + self-crushed fragments) + clast (self-crushed fragments), mbsz (0.5 mm, self-crushed fragments, carbonate, zeolite)	Trans (carbonate)	Quartz / feldspar: weak W-EX	Predominant (most grains are smaller than 2 mm)	Predominant zeolite	-	Spherule carbonate	Predominant	-	Prominent hydration softening with carbonate spherules, elongated nature along cracks	Decrease	No pseudomorphs	Lost	Lower most part of C1 shear zone. Zeolite type fault breccia.
A	1092.942	**37-12b**	**3-2: Ultracataclasite (C) hydraulic brecciation**	Perpendicular	Random fabric: matrix (carbonate) + clast (self-crushed fragments + ultracataclasite (iron hydroxide/mafic carbonate matrix in some grains + ultra fine-grained self-crushed fragments)), flow texture is predominant in ultracataclasite clast	Trans (carbonate)	Quartz / feldspar: weak W-EX	Predominant, grain size is from 10 to 20 um in ultracataclasite part.	N/A because of few numbers of remaining grains.	-	-	-	-	-	Lost	No pseudomorphs	Lost	Upper part of C2 shear zone. Carbonate type hydraulic brecciation ultracataclasite zone .

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A	1093.268	37-14	**3-3: Cataclasite (C)**	Perpendicular	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained zeolite) + clast (self-crushed fragments + zeolite), mbsz (mafic carbonate matrix + self-crushed fragments), flow texture developed in carbonate matrix of mbsz	Trans (carbonate + mafic carbonate), trans (zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Predominant, abundance of feldspars greatly decrease	N/A because of few numbers of remaining grains.	-	Spherule carbonate	Predominant	-	-	Extremely decrease	No pseudomorphs	Lost	Upper part of C2 shear zone. Carbonate dominant type ultracataclasite zone. Flow zone is developed in thick carbonate vein within zeolite matrix of ultracataclasite.
A	1093.683	37-17	**1-2/3-3: Ultracataclasite (C)**	High	Random fabric: matrix (fine-grained self-crushed fragments + ultra fine-grained zeolite) + clast (self-crushed fragments), cracks, mbsz (mafic carbonate matrix + fine-grained self-crushed fragments), flow texture developed in carbonate matrix of mbsz.	Trans (carbonate,iron hydroxide minerals)	Quartz clasts: W-EX + B-EX, feldspar clasts: N/A because of small amounts of residual clasts	Predominant, abundance of feldspars greatly decrease	N/A because of few numbers of remaining grains.	-	Most of the host biotite grains are replaced by spherule carbonates.	Predominant	-	-	Almost lost	No pseudomorphs	Lost	Upper part of C2 shear zone. Ultracataclasite zone. Thick carbonate veins within zeolite matrix of the Cataclasite. Also this sample is characterized by flow texture with iron hydroxide matrix.
A	1095.087	37-24	**2-2: Fault breccia (Z) Hydraulic brecciation**	Perpendicular	Random fabric: matrix (fine-grained zeolite + fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks (by hydraulic brecciation)	Trans (carbonate)	Quartz clasts: B-EX + W-EX, feldspar clasts: N/A because most of the grains are replaced by zeolite/albite.	Quartz grains are predominant within hydraulic brecciation texture. Feldspars are greatly decrease.	N/A because of few numbers of remaining grains. (Most grains are replaced by (zeolite/albite)	-	Spherule carbonate	Predominant	-	Replaced carbonate spherules are released into cracks	Decrease	No pseudomorphs	Lost	Lower part of C2 shear zone. Zeolite type fault breccia with hydraulic brecciation. Fault rocks in the footwall of GSJ Nojima faults show similar occurrence with this sample, that is, zeolite matrix hydraulic brecciation texture with zeolite matrix + biotite with mafic carbonate spherules.
A	1096.041	37-32	**2-1/3-2: WPAR/Cat (Z), cataclasite part (crush type)**	Horizontal	Random fabric: matrix (self-crushed fragments + carbonate) + clast (self-crushed fragments + zeolite)	No cracks	Quartz clast:s weak W-EX + B-EX, feldspar: weak W-EX	Predominant (pulverized)	Predominant zeolite replacement	In some grains	ribon carbonate	Common	-	Softening & bending of cleavages in some grains. Some cracks are filled with spherule carbonates.	Decrease	Small amount of pseudomorphs	Lost	Lower part of C2 shear zone. Zeolite type fault breccia.
A	1099.091	38-16	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture is preserved, cracks, mbsz (1 mm, ultrafine-grained zeolite + self-crushed fragments)	1. trans (zeolite), 2. trans (carbonate)	Quartz clast: weak W-EX + B-EX, feldspar: weak W-EX	only within mbsz	Fine-grained carbonates are scattered	-	Ribon zeolite, small amounts of spherule carbonates	Present	In some grains	-	Decrease	Pseudomorphs	Lost	Upper part of C3 shear zone. Coexisting type WPAR.
A	1100.489	38-28	**3-2: Cataclasite (C/Z)**	-	Random fabric: matrix (ultrafine-grained, self-crushed fragments + ultrafine-grained, mafic carbonate) + clast (self-crushed fragments), cracks	Trans (carbonate)	Quartz clasts: weak W-EX + B-EX, feldspar: weak W-EX	Predominant	Fine-grained sericites / fine-grained carbonates are scattered.	-	ribon carbonate	Predominant	-	In some grains	Extremely decrease	Small numbers of pseudomorphs	Lost	Upper part of C3 shear zone. Coexisting type WPAR.
A	1100.826	38-31	**2-2: Fault breccia (C) Hydraulic brecciation**	High	Random fabric: matrix (ultrafine-grained, self-crushed fragments + small amounts of ultrafine-grained zeolite) + clast (self-crushed fragments), cracks	Trans(carbonate, anastomosing), hydraulic brecciation	Quartz clasts: weak W-EX + B-EX, feldspar: weak W-EX	Predominant	Fine grained carbonate + zeolite	-	Ribon carbonate	Most of the residual biotites are replaced.	-	-	Lost	Small numbers of pseudomorphs	Lost	Upper part of C3 shear zone. Coexisting type WPAR.
A	1102.450	38-49	**2-2: Fault breccia (MC)**	Moderate	Random fabric: matrix (fine-grained, self-crushed fragments + fine-grained mafic carbonate) + clast (self-crushed fragments + carbonate)	Trans (carbonate), trans (zeolite)	Quartz clasts: weak W-EX + B-EX, feldspar: weak W-EX	Predominant	Zeolite, sericite, carbonate	-	Ribon carbonate	Residual biotites are completely replaced.	-	-	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	Middle part of C3 shear zone. Crushing dominated type fault breccia with zeolite and carbonate alteration. It is similar occurrence with hanging wall of GSJ core.
A	1103.051	39-2	**2-1: WPAR (C)**	-	Host framework texture is barely preserved, Cracks, mbsz (fine-grained mafic carbonate + self-crushed fragments)	Trans (euhedral zeolite + euhedral carbonate), trans (zeolite), trans (carbonate)	Quartz clasts: weak W-EX + B-EX, feldspar: weak W-EX	Common	Zeolite, sericite, carbonate	-	Ribon zeolite, Ribon carbonate	Common	In some grains	present	Decrease	Pseudomorphs	Lost	Middle part of C3 shear zone. Zeolite/carbonate coexisting type WPAR (carbonate predominant)
A	1103.997	39-13	**3-3: Ultracataclasite (C) Hydraulic brecciation**	Perpendicular	Random fabric: matrix (large amounts of fine-grained carbonate + small amounts of fine-grained self-crushed fragments) + clast (self-crushed fragments + crush type Ultracataclasite + iron hydroxide clast), mbsz (foliated clay 0.5 mm)	No cracks	N/A because of ultrafine grain sizes	Ultracataclasite becomes clasts with carbonate matrix.	-	-	-	-	-	-	Lost	-	Lost	Lower part of C3 shear zone. Ultracataclasite with carbonate matrix.
A	1104.988	39-18	**1-1: WPAR (Z)**	-	Host framework texture, cracks, mbsz (zeolite + self-crushed fragments)	Trans (euhedral zeolite), trans (small amounts of thin carbonate vein)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Pulverized Quartz with zeolite matrix (hydraulic brecciation texture) , while feldspars are replaced mostly by zeolite. Difference in Permeability is a main reason ?	Zeolite, sericite in some grains.	-	Ribon carbonate	Common	Hydration softening and bending in some grains	-	Decrease	Small numbers of pseudomorphs	Lost	Lower part of C3 shear zone. Zeolite type WPAR.

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A	1105.567	39-23	**2-1: WPAR (Z)**	-	Host framework texture, cracks, mbsz (zeolite + self-crushed fragments)	Trans (euhedral zeolite), trans (small amounts of thin carbonate vein)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Pulverized Quartz with zeolite matrix (hydraulic brecciation texture), while feldspars are replaced mostly by zeolite. Difference in Permeability is a main reason ?	Zeolite, sericite in some grains, rare carbonate dots	-	Ribon carbonate	Common	Hydration softening and bending in some grains		Decrease	Small numbers of pseudomorphs	Lost	Lower part of C3 shear zone. Zeolite type WPAR.
A	1105.958	39-27	**1-1: WPAR (C/Z)**	-	Host framework texture, cracks, mbsz (fine-grained carbonate + self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Weak fragmentation bounded by thin vein of carbonate	Sericite, small amounts of carbonate.	-	Ribon carbonate, ribon zeolite	Predominant	Hydration softening and bending in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Decrease	Small numbers of pseudomorphs	Lost	Lower part of C3 shear zone. Coexisting type WPAR.
A	1107.162	39-35	**2-1: WPAR (C)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, zeolite, carbonate)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Weak fragmentation bounded by thin vein of carbonate, quartz grains are pulverized within zeolite matrix (hydraulic brecciation)	Sericite, small amounts of carbonate.	-	Ribon carbonate, ribon zeolite	Predominant	Hydration softening and bending in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Decrease	Small numbers of pseudomorphs	Lost	WPAR between C/D shear zone. Carbonate type.
C	1112.956	40-19-1	**2-1: WPAR (C)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, zeolite, carbonate)	Trans (carbonate), intra (small amounts of zeolite)	Quartz / feldspar: weak W-EX	Weak fragmentation bounded by thin vein of carbonate, quartz grains are pulverized within zeolite matrix (hydraulic brecciation)	Sericite, small amounts of carbonate.	-	Spherule carbonate	Predominant	N/A becaouse of few residual grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Almost lost (1 grain remains)	1 grain of deformed pseudomorph	Lost	WPAR between C/D shear zone. Carbonate type.
C	1113.101	40-21A	**1-1: WPAR (C) (mbsz part)**	Moderate (mbsz)	Random fabric: matrix (dark brown carbonate, self-crushed fragments) + clast (self-crushed fragments + carbonate), cracks, mbsz (self-crushed fragments + dark brown carbonate)	Trans (carbonate), intra (small amounts of zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Predominant	Sericite, zeolite replacement, small amounts of carbonate.	-	Spherule carbonate	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	1 grain of deformed pseudomorph	Lost	WPAR between C/D shear zone. Carbonate type.
C	1113.209	40-21B	**1-1: Carbonate type WPAR (mbsz)**	High (mbsz)	Random fabric: matrix (fine-grained carbonate + fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks, mbsz (ultrafine-grained zeolite + self-crushed fragments), mbsz (fine-grained carbonate + self-crushed fragments, which overprint zeolite vein)	Trans (mafic carbonate)	Quartz: W-EX, feldspar: weak W-EX	Predominant	Replaced by dark brown carbonate spot. Replacement by Zeolite in some grains, rare sericite.	-	Spherule carbonate	Predominant	Common hydration softening	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	1 grain of deformed pseudomorph	Lost	WPAR between C/D shear zone. Carbonate type WPAR.
C	1114.101	40-30-1	**2-1: WPAR (C)**	-	Host framework texture is barely preserved. Cracks, mbsz (dark brown carbonate + self-crushed fragments), mbsz (zeolite + self-crushed fragments)	Trans (mafic carbonate)	Quartz: W-EX + B-EX, feldspar: wavy + partly B-EX besides mbsz.	Predominant, hydraulic brecciation texture in quartz	Predominant zeolite near the Zeolite vein, fine grained carbonates in other parts	-	Spherule carbonate	Predominant	Common hydration softening	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	No pseudomorphs	Lost	WPAR between C/D shear zone. Carbonate type.
C	1114.101	40-30-2	**2-1: WPAR (Z)**	Perpendicular (mbsz)	Host framework texture. Cracks, 1. mbsz (fine-grained zeolite + small amounts of self-crushed fragments + Carbonate vein), 2. mbsz (self-crushed fragments + fine-grained mafic carbonate)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX in some grains, feldspar: weak W-EX	Predominant, hydraulic brecciation texture in quartz	Predominant zeolite near the Zeolite vein, fine grained carbonates in other parts. Minor sericite replacement	-	Spherule carbonate, ribon zeolite vein in some grains	Predominant	Common hydration softening, some grains contain bent zeolite vein	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	1 grain of deformed pseudomorph	Lost	WPAR between C/D shear zone. Zeolite type.
C	1114.237	40-31	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture. Cracks, mbsz (fine-grained dark brown material + euhedral zeolite + carbonate + self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX in some grains, feldspar: weak W-EX	Predominant in mbsz. Hydraulic brecciation texture including some quartz	Small amounts of carbonate and zeolite, and sericite.	-	Spherule carbonate, ribon zeolite vein in some grains	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	Pseudomorphs	Lost	WPAR between C/D shear zone. Coexisting type.
C	1114.664	40-34	**3-3: Ultracataclasite (Z)**	Moderate (?)	Random fabric: matrix (dominant zeolite + self-crushed fragments + carbonate) + clast (self-crushed fragments + (zeolite + carbonate)), cracks, mbsz (mafic, dark brown carbonate + fine-grained self-crushed fragments)	Trans (mafic carbonate)	Only quartz grains are remaining: predominant W-EX	Predominant	Almost lost	-	-	-	-	-	Lost	No pseudomorphs	Lost	U cat zone between C/D shear zone. Zeolite type (minor).

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C	1116.273	**41-4+**	**1-1: WPAR (C)**	-	Host framework texture, cracks, mbsz (dark brown carbonate + fine-grained self-crushed fragments)	Trans (zeolite), trans (carbonate)	Quartz / feldspar: weak W-EX + weak B-EX	Hydraulic brecciation texture including some quartz. Fragmentation in mbsz	Small amounts of carbonate and zeolite, sericite	-	Spherule carbonate, ribon zeolite vein	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	WPAR between C/D shear zone. Carbonate type.
C	1117.268	**41-11**	**0-1: WPAR (C/Z)**	-	Host framework texture, cracks, mbsz (fine-grained zeolite + fine-grained self-crushed fragments)	Trans (zeolite), trans (carbonate)	Quartz / feldspar: weak W-EX + weak B-EX	Hydraulic brecciation texture including some quartz. Fragmentation in mbsz	Carbonate, zeolite, sericite	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	Pseudomorphs	Lost	WPAR between C/D shear zone. Coexisting type.
C	1118.731	**41-18**	**1-1: WPAR (C)**	-	Host framework texture. Cracks, 1. mbsz (clay + self-crushed fragments + carbonate), 2. mbsz (dark brown fine-grained carbonate + self-crushed fragments)	Trans (carbonate)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	Quartz grains are in hydraulic brecciation texture with carbonate or zeolite. Feldspars are not so brecciated.	Predominant carbonate spots	-	Spherule carbonate	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	Pseudomorphs	Lost	Upper part of D1 shear zone. Carbonate type WPAR.
C	1120.668	**41-31-2**	**2-1c: WPAR (MC)**	-	Host framework texture is barely preserved. Cracks, mbsz (dark brown fine-grained carbonate + self-crushed fragments weak flow texture in some grains), mbsz (zeolite + self-crushed fragments + small amounts of dark brown carbonate)	Trans (zeolite) + trans (carbonate thin vein)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	Predominant hydraulic brecciation texture including fragmented quartz.	Predminant carbonate spots	-	Spherule carbonate	Predominant	Hydration softening in some grains	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Extremely decrease	Pseudomorphs	Lost	Upper part of D1 shear zone. Carbonate type WPAR.
C	1121.013	**41-34-2**	**1-1: WPAR (C) (in mbsz)**	Moderate	Random fabric: matrix (fine-grained dark brown /mafic carbonate + fine-grained self-crushed fragments + small amounts of foliated clay) + clast (self-crushed fragments + mafic carbonate)	Trans (mafic carbonate)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	Predominant	Predominant carbonates spots, zeolite in some grains	-	Spherule carbonate (one grain remains)	-	-	-	almost lost	No pseudomorphs	Lost	Upper part of D1 shear zone. Carbonate type WPAR. Minor clay shear zone showing flow structure.
C	1121.192	**41-35**	**1-1: WPAR (MC) (in fine grained Xenolith)**	High	Host framework texture. Cracks, mbsz (dark brown fine-grained material (seismic slip surface?) + self-crushed fragments), mbsz (brown fragmented material + self-crushed fragments + mafic carbonate clast + small amounts of clay)	Trans (mafic carbonate)	Quartz / feldspar: weak W-EX	Less prominent	Carbonate spots, sericite in some grains, iron hydroxide spots in one grain.	-	Spherule carbonate	Predominant	hydration softening, kink bands in 1 grain	Replaced carbonate spherules are released into cracks. Elongation of residual biotite within cracks	Decrease	Deformed pseudomorphs	Lost	Upper part of D1 shear zone. Carbonate type WPAR (Xenolith).
C	1121.422	**41-37**	**2-1: WPAR (MC) (in breccia)**	Moderate	Random fabric: matrix (fine-grained dark brown mineral + fine-grained self-crushed fragments + clay) + clast (self-crushed fragments + mafic carbonate), mbsz (ultracataclasite vein, dark brown fine-grained material, self-crushed fragments), cataclastic flow texture develops close to ultracataclasite zone.	No vein	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant, especially in ultracataclasite zone.	Spots of fine grained carbonate	Change color into grayish white (chlorite?)	Spherule carbonate	Predominant	Hydration softening	A few residual grains of carbonate spherules are released into cracks.	Almost lost	No pseudomorphs	Lost	Just above the D1 shear zone. Mafic carbonate type WPAR (contianing ultracataclasite zone).
C	1121.577	**41-38**	**2-2: Fault breccia (foliated) (MC)**	High	Random fabric: matrix (fine-grained self-crushed fragments + clay) + clast (self-crushed fragments + mafic carbonate), mbsz (Ultracataclasite, clay in center zone)	No vein	Quartz: W-EX + B-EX, feldspar clasts: W-EX	Predominant, espeically in ultracataclasite zone.	Spots of fine grained carbonate in some grains, zeolite	Change color into grayish white (chlorite?)	Spherule carbonate	Predominant	Hydration softening	A few residual grains of carbonate spherules are released into cracks.	Almost lost	No pseudomorphs	Lost	Upper part of D1 shear zone. Mafic carbonate type WPAR. Dominant Cataclastic flow in ultracataclasite zone (containing clay in center zone).
C	1122.426	**42-4-1**	**1-2: WPAR (C)**	Moderate	Host framework texture. Cracks, mbsz (self-crushed fragments, carbonate)	Trans (carbonate)	Quartz: W-EX + blocky texture, feldspar: weak W-EX, B-EX besides mbsz	common besides mbsz	Spots of fine grained carbonates	Change color into grayish white (chlorite?)	Spherule carbonate	Predominant	Hydration softening	A few residual grains of carbonate spherules are released into cracks.	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	Upper part of D1 shear zone. Carbonate type WPAR. Typical sample of carbonate type.
C	1123.201	**42-11**	**2-2: Ultracataclasite (MC)**	Moderate	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate) + clast (self-crushed fragments + mafic carbonate), mbsz (micro shear zone containing clay)	Trans (carbonate)	Quartz: W-EX, feldspar: weak W-EX, feldspars were broken and quartz were plasticaly strained.	Dominant	Spots of fine grained carbonates	Change color into grayish white (chlorite?)	-	-	-	Extremely fragmented and involved into matrix	Almost lost	No pseudomorphs	Lost	Middle part of D1 shear zone. Mafic carbonate type Ultracataclasite. Dominant self-crushed fragments with few zeolite, mafic carbonate veins.
C	1125.696	**42-30-1**	**2-3: Ultracataclasite (C/Z)**	Moderate	Random fabric: matrix (fine-grained self-crushed fragments + large amounts of fine-grained zeolite) + clast (self-crushed fragments, fragments of zeolite vein), cracks	Trans (carbonate), predominant	Quartz: W-EX + B-EX, feldspar: W-EX	Dominant	Zeolite replacement (in some grains), spots of fine grained carbonates	Change color into grayish white (chlorite?)	-	-	-	Extremely fragmented and involved into matrix	Almost lost	No pseudomorphs	Lost	Middle part of D1 shear zone. Coexisting type ultracataclasite. Dominant in zeolite alteration with minor self-crushed fragments + carbonate part.This sample may represent boundary surface. Carbonate vein forms a hydraulic brecciation texture including boundary zone.

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C	1126.090	**42-34,5**	**2-3: Fault breccia (C) hydraulic brecciation**	Moderate	Randam fabric: matrix (carbonate) + clast (self-crushed fragments), cracks, mbsz (self-crushed fragments + carbonate)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Hydraulic brecciation	Spots of fine grained carbonates	-	Spherule mafic carbonate	Predominant	Hydration softening	A few residual grains of carbonate spherules are released into cracks.	Extremely decrease	Deformed pseudomorphs	Lost	Middle part of D1 shear zone. Carbonate type fault breccia with hydraulic brecciation texture.
C	1127.972	**43-11**	**1-2: Altered intrusive rock (C/Z)**	High	Host framework texture, cracks, mbsz (self-crushed fragments + dark brown fine-grained material, R/S texture present)	Trans (carbonate), trans (zeolite)	Quartz: fine grain size due to intrusive body origin, W-EX (?), feldspar: weak W-EX	N/A becaouse of very fine grain size	Spots of fine grained carbonates	-	Spherule mafic carbonate (brown interference color)	Predominant	-	A few residual grains of carbonate spherules are released into cracks.	Extremely decrease	Deformed pseudomorphs	Lost	Middle part of D1 shear zone. Altered intrusive rock (coexisting type).
A	1128.232	**43-14**	**2-2: Fault breccia (C/Z) (altered and brecciated intrusive rock)**	-	Host framework texture is barely preserved, cracks, mbsz (dark brown fine-grained material + self-crushed fragments, flow texture)	Trans (carbonate), which cut the mbsz with moderate dips, trans (zeolite)	Quartz: fine grain size due to intrusive body origin, W-EX (?), feldspar: weak W-EX	N/A becaouse of very fine grain size	Spots of fine grained carbonates, small amounts of sericite, zeolite replacement in some grains	-	Spherule mafic carbonate (brown interference color)	Predominant	-	A few residual grains of carbonate spherules are released into cracks.	Extremely decrease	No pseudomorphs	Lost	Lower part of D1 shear zone. Sheared and altered intrusive rocks (coexisting type)
A	1128.370	**43-16**	**2-2: Fault breccia (C/Z) (altered and brecciated intrusive rock)**	High (vein)	Random fabric: matrix (self-crushed fragments + fine-grained dark brown material + fine-grained mafic carbonate) + clast (self-crushed fragments + zeoliteagregates), cracks, mbsz (carbonate, self-crushed fragments, zeolite, dominant flow texture)	Trans (carbonate), trans (zeolite)	Quartz: fine grain size due to intrusive body origin, W-EX (?), feldspar: weak W-EX	N/A becaouse of very fine grain size	Spots of fine grained carbonates, small amounts of sericite, zeolite replacement in some grains	-	Spherule mafic carbonate (brown interference color)	Predominant	-	A few residual grains of carbonate spherules are released into cracks.	Extremely decrease	No pseudomorphs	Lost	Lower part of D1 shear zone. Sheared and altered intrusive rocks (coexisting type)
A	1129.121	**43-20**	**2-3: Fault breccia (Z)**	Low	Random fabric: matrix (self-crushed fragments + dominant zeolite) + clast (self-crushed fragments + zeolite), cracks, mbsz (self-crushed fragments + fine-grained carbonate)	Trans (carbonate), trans (zeolite)	Quartz: W-EX, feldspar: equant	Predominant	Zeolite, rare sericite, and carbonate spots in some grains	-	Spherule carbonate	Predominant	-	A few residual grains of carbonate spherules are released into cracks.	Almost lost	Small numbers of deformed pseudomorphs	Lost	Lower part of D1 shear zone. Zeolite type fault breccia, containing carbonate veins. Wedge shaped crystal showing high interference color (yellow) present.
A	1129.498	**43-23**	**2-2: Fault breccia (Z) (C overprints)**	Moderate	Random fabric: matrix (self-crushed fragments + dominant zeolite + fine-grained carbonate) + clast (self-crushed fragments + zeolite + carbonate), cracks, mbsz (self-crushed fragments + dark brown fine-grained material + fine-grained carbonate, dominant flow texture)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + weak B-EX, feldspar: weak W-EX	Predominant, especially in mbsz	Zeolite, rare sericite, and carbonate spots in some grains	-	Spherule carbonate	Predominant	-	A few residual grains of carbonate spherules are released into cracks.	Almost lost	Small numbers of deformed pseudomorphs	Lost	Lower part of D1 shear zone. Zeolite type fault breccia, containing carbonate veins.
C	1131.662	**43-36**	**1-2: WPAR (C/Z)**	Moderate	Host framework texture, cracks, mbsz (self-crushed fragments, fine-grained carbonate, small amounts of clay)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Common	Sericite, zeolite, carbonate spots in some grains	-	Spherule carbonate	Predominant	Small amount of softening bending	A few residual grains of carbonate spherules are released into cracks.	Almost lost	Small numbers of pseudomorphs	Lost	Lower part of D1shear zone. Coexisting type WPAR.
C	1133.306	**44-12-1**	**1-2: WPAR originated from intrusive rock (C/Z)**	-	Host framework texture, cracks, mbsz (dominant zeolite, carbonate, self-crushed fragments)	Trans (zeolite), trans (carbonate)	Quartz: N/A because of very fine grained nature of intrusive rocks, feldspar: weak W-EX	N/A becaouse of very fine grain size	Predominant sericite, zeolite in some grains	-	A few residual grains are repleced by brown unclear minerals.	-	-	-	Lost	Small numbers of pseudomorphs	Lost	Lower part of D1 shear zone. Weakly sheared, altered intrusive rocks.
C	1133.770	**44-16**	**2-2: Fault breccia (Z)**	-	Host framework texture is barely preserved, cracks, mbsz (dark brown fine-grained material + self-crushed fragments, ambiguous flow texture in some parts)	Trans (carbonate), trans (zeolite)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Common	Zeolite, spots of fine-grained carbonates	-	Spherule carbonate	Predominant	Kink bands in two grains (softening and bending)	-	Almost lost	No pseudomorphs	Lost	Lower part of D1 shear zone. Coexisting type fault breccia.
C	1133.936	**44-17**	**3-3: Ultracataclasite (C/Z)**	Moderate	Random fabric: matrix (self-crushed fragments + zeolite + small amounts of clay) + clast (self-crushed fragments + zeolite agregates), cracks, mbsz (dark brown fine-grained matrix + fine-grained self-crushed fragments + foliated clay in some parts)	Trans (carbonate)	Quartz: W-EX, feldspar: N/A due to few residual grains	Predominant, especially in mbsz	N/A due to few residual grains	-	Spherule carbonate	Predominant	Kink bands in one grain (softening and bending)	-	Almost lost	No pseudomorphs	Lost	Lower part of D1 shear zone. Coexisting type Ultracataclasite.
C	1135.248	**44-26-1A**	**3-3f: Ultracataclasite (MC)**	High	Random fabric: matrix(fine-grained carbonate + self-crushed fragments) + clast (self-crushed fragments + carbonate), cracks, mbsz (fine-grained carbonate, hydraulic brecciation in some parts, aggfregates of carbonate + self-crushed fragments, weak flow texture)	Trans (carbonate)	Quartz, feldspar: Weak W-EX (less meanings due to very fine grain size)	Predominant	N/A due to few residual grains	-	-	-	-	-	Lost	No pseudomorphs	Lost	Lower part of D1 shear zone. Mafic carbonate type ultracataclasite. Flow texture is prominent where fine grained carbonates dominate.
C	1135.248	**44-26-1B**	**3-3f: Ultracataclasite (MC)**	High	Random fabric: matrix (fine-grained carbonate + self-crushed fragments) + clast (self-crushed fragments, aggregates of clasts with zeolite matrix + carbonate), mbsz (fine-grained carbonate, flow texture of dark brown fine-grained material, carbonate + aggregates of self-crushed fragments)	-	Quartz, feldspar: Weak W-EX (less meanings due to very fine grain size)	Predominant	N/A due to few residual grains	-	-	-	-	-	Lost	No pseudomorphs	Lost	Lower part of D1 shear zone. Mafic carbonate type ultracataclasite. Flow texture is prominent where fine grained carbonates dominate.

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C	1135.495	**44-27-1**	**3-3: Ultracataclasite (MC)**	High	Random fabric: matrix (fine-grained carbonate + fine-grained, self-crushed fragments) + clast (self-crushed fragments, carbonate), cracks, mbsz (dark brown fine-grained material, fine-grained carbonate, fine-grained self-crushed fragments)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Spots of fine grained carbonates, zeolite	-	-	-	-	-	Lost	No pseudomorphs	Lost	Lower part of D1 shear zone. Mafic carbonate type ultracataclasite. Ultracataclasite cut another ultracataclasite layer.
A	1137.425	**45-6-2**	**2-2: Ultracataclasite (Z)**	Moderate	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained zeolite) + clast (self-crushed fragments), cracks	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Zeolite, small amounts of sericite	-	Spherule carbonate, massive carbonate	Predominant	Hydration softening	A few residual grains of carbonate are released into cracks.	Almost lost	One grain of deformed pseudomorph	Lost	Lower part of D1 shear zone. Zeolite type ultracataclasite. Carbonate veins present.
C	1138.628	**45-13**	**2-2: Fault breccia (C)**	-	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate +clast (self-crushed fragments), cracks, mbsz (self-crushed fragments + dark brown fine-grained material, weak flow texture)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Sericite, spots of fine grained carbonates, zeolites in some grains	-	Spherule carbonate	Predominant	Hydration softening	A few residual grains of carbonate are released into cracks.	Almost lost	One grain of deformed pseudomorph	Lost	Upper most part of D2 shear zone. Carbonate type fault breccia, overprinting Zeolite type alteration.
C	1139.816	**45-18-**	**2-2: Fault breccia (MC/IH) (overprinting (Z))**	High	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate + fine-grained zeolite) + clast (self-crushed fragments + zeoliteagregates + carbonate), cracks, mbsz (fine-grained self-crushed fragments + dark brown fine-grained material + carbonate, flow texture)	Trans (carbonate), hydraulic brecciation	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Sericite, zeolite, spots of fine grained carbonates	-	Spherule carbonate, massive carbonate	Predominant	Hydration softening	A few residual grains of carbonate are released into cracks.	Almost lost	Some grains of deformed pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate / iron hydroxide type fault breccia, overprinting Zeolite type alteration. Samples from just above PT layer.
C	1140.031	**45-19-**	**2-2: Ultracataclasite (MC) (overprinting (Z))**	Moderate	Ultracataclasite part: Random fabric: matrix (self-crushed fragments + fine-grained zeolite + dark brown fine-grained material + carbonate) + clast (self-crushed fragments + zeoliteagregates), cracks. Intrusive body part: Host framework texture, cracks, mbsz (self-crushed fragments, dark brown fine-grained material)	Trans (carbonate), trans (zeolite, only in intrusive body)	Ultracataclasite part: Quartz: W-EX + B-EX, feldspar: N/A due to few residual grains	Predominant in ultracataclasite zone, ambiguous in intrusive rocks	Ultracataclasite part: a few residual grains show zeolite alteration, Intrusive rocks: zeolite, carbonate spots in some grains	-	-	-	-	-	Lost	Two grains of deformed pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate type ultracataclasite, overprinting zeolite type alteration. Samples from just above PT layer.
C	1140.163	**45-19A**	**2-2: Ultracataclasite (MC)**	High	Random fabric: matrix (self-crushed fragments + fine-grained zeolite +dark brown fine-grained material + mafic carbonate) + clast (self-crushed fragments + carbonateagregates), cracks, mbsz (self-crushed fragments + dark brown fine-grained material, flow texture)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Hydraulic brecciation with carbonate matrix	Zeolite, carbonate spots	-	Spherule carbonate, massive carbonate	Predominant	Hydration softening	A few residual grains of carbonate are released into cracks.	Almost lost	Two grains of deformed pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate type ultracataclasite, overprinting zeolite type alteration. Samples from just above PT layer.
C	1140.163	**45-19B**	**2-2: Fault breccia (MC)**	-	Random fabric: matrix (self-crushed fragments + dark brown fine-grained material + mafic carbonate) + clast (self-crushed fragments + carbonateagregates), cracks, mbsz (dark brown fine-grained materialagregates similar to PT (flow texture) + fine-grained mafic carbonate + small amount of fine-grained self-crushed fragments)	Trans (carbonate), hydraulic brecciation	Quartz: W-EX + B-EX, feldspar: W-EX	Hydraulic brecciation with carbonate matrix	Zeolite, carbonate spots	-	Spherule carbonate, massive carbonate	Predominant	Hydration softening	N/A due to few residual grains	Almost lost	Small numbers of pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate type ultracataclasite. Thin, brown ultracalaclasite veins involving PT clasts presents. In a PT clast, layered structure (similar to the flow lines of turbulance) is observed. Samples from just above the PT layer.
C	1140.218	**45-20**	**2-2: Ultracataclasite (MC) (overprinting (Z))**	High	In ultracataclasite: Random fabric: matrix (self-crushed fragments + fine-grained zeolite + minor amounts of dark brown fine-grained material + minor amounts of clay) + clast (self-crushed fragments + zeolite), cracks. In Intrusive body: random fabric: matrix (dark brown fine-grained carbonate) + clast (zeolite agregates, self-crushed fragments), cracks, mbsz (zeolite, small amounts of self-crushed fragments, dark brown fine-grained material)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Zeolite replaced , sericite in some grains	-	Brown massive carbonate	Predominant	Hydration softening	N/A due to few residual grains	Almost lost (only one grain remains)	No pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate type fault breccia, overprinting zeolite type alteration. Samples from just above the PT layer.

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C	1140.366	**45-21**	**2-2: Fault breccia (MC/IH)**	Low	Random fabric: matrix (self-crushed fragments + dark brown fine-grained material + fine-grained mafic carbonate+ small amounts of clay) + clast (self-crushed fragments), cracks, mbsz (matrix of dark brown fine-grained self-crushed fragments + ultrafine-grained, self-crushed fragments)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Sericite, Spots of fine grained carbonates		Brown spherule carbonate	Predominant	Hydration softening	N/A due to few residual grains	Almost lost	Small numbers of deformed pseudomorphs	Lost	Upper part of D2 shear zone. Mafic carbonate type fault breccia. Samples from just above PT layer.
C	1140.662	**45-24-1sp**	**3-3f: Ultracataclasite (IH/MC) (PT clast layer)**	High	In ultracataclasite: Random fabric: matrix (dark brown opaque material + fine-grained carbonate + fine-grained self-crushed fragments) + clast (self-crushed fragments + mafic carbonate). in PT clast layer, Random fabric: matrix (fine-grained mafic carbonate + fine-grained self-crushed fragments + small amounts of foliated clay) + clast (PT, rounded, self-crushed ultrafine fragments)	-	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. Mafic carbonate / iron hydroxide type ultracataclasite + PT clast layer
C	1140.662	**45-24-1xy (ls)**	**3-3f: Ultracataclasite (MC) (PT clast layer)**	High	Random fabric: matrix (fine-grained mafic carbonate + fine-grained self-crushed fragments + small amounts of foliated clay) + clast (PT, rounded, self-crushed ultrafine fragments)	-	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. PT clast layer. Thin section parallel to foliation. Arrangements of PT clasts are ambiguous.
C	1140.662	**45-24-1xz**	**3-3f: Fault breccia and Ultracataclasite (MC) (PT clast layer in ultracataclasite)**	High	In FB: Random fabric: matrix (dark brown opaque material + ultrafine-grained mafic carbonate + ultra fine-grained self-crushed fragments) + clast (self-crushed fragments + aggregates of fine-grained self-crushed fragments), cracks. In ultracataclasite: matrix (same as above) + clast (zeolite + carbonate), Flow texture. In PT clast layer: (same as above) + matrix (small amounts of clay), injection texture	FB part: trans (carbonate) hydraulic brecciation	FB part: quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Sericite, zeolite	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. Gradual change in texture from fault breccia, ultracataclasite, PT layer Ultracataclasite can be observed in this thin section. Mafic carbonate type. Injection sturcture is observed in PT clast layer.
C	1140.662	**45-24-1yz**	**3-3f: Fault breccia (MC), and foliated ultracataclasite (IH) (PT clast layer)**	High	In FB: Random fabric: matrix (dark brown opaque material + ultrafine-grained mafic carbonate) + clast (intrusive body, self-crushed fragments + aggregates of fine-grained self-crushed fragments), cracks. In Ultracataclasite: matrix (same as above) + clast (carbonate), dominant flow layer. In PT clast layer: same as above + matrix (small amounts of clay), extremely decrease in grain size	FB part: trans (carbonate)	FB part: quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Sericite, zeolite	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. Gradual change in texture from fault breccia, ultracataclasite, PT layer Ultracataclasite can be observed in this thin section. Mafic carbonate type. Flow deformation is concentrated where brown opaque minerals are precipitated.
C	1140.685	**45-24-2xz(ls)**	**3-3f: Ultracataclasite (MC) (PT clast layer)**	High	Random fabric: matrix (ultrafine-grained mafic carbonate + ultrafine-grained self-crushed fragments + small amounts of foliated clay) + clast (PT, rounded, self-crushed ultrafine fragments)	-	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. PT clast layer.
C	1140.720	**45-25-1xz(ls)**	**3-3f: Ultracataclasite (MC) (PT clast layer)**	High	Random fabric: matrix (ultrafine-grained mafic carbonate + ultrafine-grained self-crushed fragments + small amounts of foliated clay) + clast (PT, rounded, self-crushed ultrafine fragments)	-	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone. PT clast layer.
C	1140.960	**45-25-2xz(ls)**	**3-3f: Foliated Ultracataclasite (MC/IH) (overprinting (Z)).**	N/C	Foliated fabric matrix (dark brown fine-grained material, fine-grained self-crushed fragments, fine-grained mafic carbonates, small amounts of clay) + clast (self-crushed fragments, zeolite aggregates, carbonate aggregates). Folded flow texture (great)	-	Quartz: relatively equant, feldspar: relatively equant	Predominant	Zeolite predominant	-	-	-	-	-	Lost	-	Lost	Middle partof D2 shear zone (just beneath the PT clast layer). Mafic carbonate / iron hdyroxide type ultracataclasite, characterized by folded flow foliations.
C	1141.158	**45-25-3(2-) sp**	**3-3f: Foliated Ultracataclasite (MC/IH) (overprinting (Z))**	N/C	Foliated fabric: matrix (dark brown fine-grained material, fine-grained self-crushed fragments, fine-grained mafic carbonates, small amounts of clay) + clast (self-crushed fragments, zeolite aggregates, carbonate aggregates)	-	Quartz: relatively equant with some W-EX grains, feldspar: a few residual grains show relatively equant extinction	Predominant	Zeolite predominant	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone (just beneath the PT clast layer). Iron hydoroxide type foliated ultracataclasite.

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C	1141.244	**45-26**	**3-3f: Ultracataclasite (MC/IH) (overprinting (Z)).**	High	Random fabric: matrix (dark brown fine-grained material, fine-grained self-crushed fragments, fine-grained mafic carbonate, small amounts of clay) + clast (self-crushed fragments, zeolite aggregates, carbonate aggregates), mbsz (dark brown fine-grained material, ultrafine-grained self-crushed fragments, ultrafine grained mafic carbonates)	-	Quartz: W-EX, feldspar: W-EX in a few residual grains	Predominant	Zeolite predominant	-	-	-	-	-	Lost	-	Lost	Middle part of D2 shear zone (just beneath the PT clast layer). Iron hydroxide type ultracataclasite. Prominent random fabric contrasting to the samples described above.
C	1141.532	**45-27-2**	**2-2: Fault breccia (C/Z)**	Moderate	Random fabric: matrix (fine-grained zeolite, fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks, mbsz (dark brown fine-grained material, fine-grained mafic carbonates, fine-grained self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz: weak W-EX, feldspar: weak W-EX	Predominant	Zeolite predominant, carbonate spots in some grains.	-	Spherule carbonate	Predominant	Kink bands in some grains	-	Almost lost	-	Lost	Lower part of D2 shear zone (just beneath the PT clast layer). Zeolite type fault breccia. Small amounts of carbonates overprint zeolite alteration. Originated from intrusive body ?
C	1141.603	**45-28**	**2-2: Fault breccia (Z)**	-	Random fabric: matrix (fine-grained zeolite, fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks, mbsz (dark brown fine-grained materials, fine-grained mafic carbonates, fine-grained self-crushed fragments, thin veins of clay), anastomosing occurrence.	Trans (carbonate)	Quartz: weak W-EX, feldspar: weak W-EX	Predominant	Zeolite predominant, carbonate spots in some grains	-	-	-	-	-	Lost	-	Lost	Lower part of D2 shear zone (just beneath the PT clast layer). Zeolite type fault breccia. Small amounts of mafic carbonates overprint zeolite alteration. Originated from intrusive body ?
C	1142.199	**45-32-2**	**2-2: Fault breccia (Z)**	-	Random fabric: matrix (fine-grained zeolite, fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks, mbsz (dark brown fine-grained material, fine-grained mafic carbonate, fine-grained self-crushed fragments, foliated clay)	Trans (carbonate)	Quartz: W-EX, feldspar: weak W-EX	Predominant	Zeolite predominant, grain carbonate spots in some grains. Tatoo like patterns are observed.	-	Spherule carbonate	Predominant	Predominant hydration softening	Fragmentated and released into cracks	Almost lost	-	Lost	Lower part of D2 shear zone (just beneath the PT clast layer). Zeolite type fault breccia. Small amounts of mafic carbonates overprint zeolite alteration. Less pulverized nature than above samples. Originated from intrusive body ?
C	1143.555	**46-7-1**	**2-2: Fault breccia (Z)**	-	Random fabric: matrix (fine-grained zeolite, fine-grained self-crushed fragments) + clast (self-crushed fragments), cracks, mbsz (dark brown fine-grained material, fine-grained mafic carbonate, fine-grained self-crushed fragments, foliated clay)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Predominant (not predominant if this is originated from intrusive body)	Zeolite predominant, carbonate spots in some grains.	-	Spherule carbonate	Predominant	Predominant hydration softening	Fragmentated and released into cracks	Almost lost	-	Lost	Lower part of D2 shear zone (beneath the PT clast layer). Zeolite type fault breccia. Small amounts of carbonate overprint. Less pulverized.
C	1143.686	**46-7-2,3(sp)**	**3-3: Fault breccia (MC/IH) (overprinting (Z))**	N/C	Random fabric: matrix (dark brown fine-grained material, fine-grained mafic carbonate, fine-grained self-crushed fragments) + clast (self-crushed fragments + mafic carbonate), mbsz (dark brown ultrafine-grained material, ultrafine-grained self-crushed fragments), mbsz (foliated clay)	-	Quartz: W-EX + B-EX, feldspar: weak W-EX	Predominant	Zeolite predominant, carbonate spots in some grains.	-	Spherule carbonate	Predominant	Predominant hydration softening	Fragmentated and released into cracks	Almost lost	-	Lost	Lower part of D2 shear zone (beneath the PT clast layer). Mafic carbonate / iron hydroxide type fault breccia.
C	1144.113	**46-9sp**	**3-3f: Ultracataclasite (MC) (overprinting (Z))**	N/C	Random fabric: matrix (dark brown fine-grained material, fine-grained mafic carbonate, self-crushed fragments) + clast (self-crushed fragments, mafic carbonate, aggregates of dark brown fine-grained material, zeolite aggregates), mbsz (foliated clay, dark brown fine-grained carbonate, ultrafine-grained self-crushed fragments)	-	Quartz: W-EX, feldspar: N/A due to few residual grains	Predominant	A few residual grain may be mostly replaced to zeolite.	-	-	-	-	-	Lost	-	Lost	Lower part of D2 shear zone. Mafic carbonate type ultracataclasite.
C	1144.178	**46-10sp**	**2-2: Fault breccia (MC/IH)**	N/C	Random fabric: matrix (dark brown fine-grained material, fine-grained mafic carbonate, self-crushed fragments) + clast (self-crushed fragments), cataclasitc flow in some part	-	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Spots of fine grained carbonate	-	-	-	-	-	Lost	-	Lost	Lower part of D2 shear zone. Mafic carbonate type fault breccia.
C	1144.425	**46-12**	**2-2: Fault breccia (MC/IH)**	Moderate	Random fabric: matrix (dark brown fine-grained material, fine-grained mafic carbonate, self-crushed fragments) + clast (self-crushed fragments), cataclastic flow in some part, mbsz (fine-grained self-crushed fragments, carbonate), hydraulic brecciation in some part.	-	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant	Spots of fine grained carbonate	-	-	-	-	-	Lost	-	Lost	Lower part of D2 shear zone. Mafic carbonate type fault breccia.
C	1146.442	**46-33**	**1-2: WPAR (C)**	High (mbsz)	Host framework texture is barely preserved, cracks, mbsz (self-crushed fragments, dark brown fine-grained material)	Trans (carbonate), hydraulic brecciation	Quartz: W-EX + B-EX, feldspar: W-EX	Predominant in hydraulic brecciation zone and mbsz	Spots of fine grained carbonate in some grains	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening	-	Extremely decrease	-	Lost	Lowermost part of D2 shear zone. Carbonate type WPAR.

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C	1146.508	**46-34**	**2-2: Fault breccia (Z) (overprinted by (C))**	High (mbsz)	Random fabric: matrix (zeolite, self-crushed fragments) + clast (self-crushed fragments + zeolite aggregates), cracks	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX (a few residual grains due to zeolite replacement)	Predominant	Replacemnt of zeolite is predominant	-	Spherule carbonate	Predominant	Hydration softening	-	Extremely decrease	-	Lost	Lowermost part of D2 shear zone. Zeolite type fault breccia. Mafic carbonate overprints.
C	1147.617	**47-6**	**1-1: WPAR (C)**	-	Host framework texture, cracks, mbsz (self-crushed fragments), weak S-C fabric.	Trans (carbonate), overprinting mbsz (self-crushed fragments)	Quartz: weak W-EX, feldspar: weak W-EX	Restricted within mbsz	Spots of fine grained carbonate	-	Spherule carbonate, minor amounts of ribon zeolite	Predominant	Hydration softening	-	Extremely decrease	No pseudomorphs	Lost	Just beneath the D shear zone. Carbonate type WPAR.
C	1147.863	**47-12**	**1-1: Zeolite type (less altered) WPAR (Z)**	-	Host framework texture, cracks, mbsz (self-crushed fragments, zeolite)	Trans(carbonate thin vein), trans (zeolite thin vein)	Quartz: weak W-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite predominant	-	Ribon carbonate, ribon zeolite	Rare	Kink band	-	decrease	Pseudomorphs	Lost	Just beneath the D shear zone. Zeolite type WPAR.
C	1148.153	**47-15**	**1-1: Carbonate type WPAR (C)**	Perpendicular (mbsz)	Host framework texture is barely preserved, cracks, mbsz (self-crushed fragments, biotite and felspars remains in the matrix, pulverization type)	Trans (carbonate), overprinting mbsz (self-crushed fragments)	Quartz: W-EX + weak B-EX, feldspar: weak W-EX	Restricted within mbsz	Spots of fine grained carbonate	-	Spherule carbonate	Common	Hydration softeningpresent	—	Extremely decrease	No pseudomorphs	Lost	Just beneath the D shear zone. Upper part of fault minor breccia zone. Carbonate type WPAR.
C	1149.398	**47-35sp**	**3-3: Ultracataclasite (MC)**	N/C	Random fabric: matrix (fine-grained self-crushed fragments + dark brown fine-grained material + fine-grained mafic carbonate) + clast (self-crushed rounded fragments + zeolite + carbonate aggregates)	-	Quartz: W-EX, feldspar: N/A due to few residual grains	Restricted within mbsz	Zeolite replacement in a few residual grains	-	-	-	-	-	Lost	No pseudomorphs	Lost	Beneath the D shear zone. Mafic carbonate type, minor ultracataclasite zone
C	1150.532	**47-51**	**1-1: WPAR (MC/IH)**	Horizontal (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, fine-grained iron hydroxide, mafic carbonate)	trans (carbonate)	Quartz / feldspar: W-EX	Restricted within mbsz	spots of fine grained carbonate, predominant	-	thin ribon zeolite and carbonate	Rare	Kink band predominant	Restricted within mbsz	decrease	Pseudomorphs	Lost	Beneath the D shear zone. Mafic carbonate / iron hydroxide type WPAR.
C	1151.394	**47-64**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, fine-grained zeolite, iron hydroxide minerals, mafic carbonate)	Trans (carbonate)	Quartz: W-EX + B-EX, feldspar: W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate	-	Spherule carbonate	Predominant	Small amounts of kink bands are remaining. Hydration softening	In some grains, fragmentation after carbonate alteration	Decrease	No pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR. Carbonate type alteration overprints zeolite alteration.
C	1151.394	**47-64B**	**1-1: WPAR (C/Z)**	-	Host framework texture, cracks	Trans (carbonate), trans (zeolite)	Quartz: weak W-EX + weak B-EX, feldspar: weak W-EX	-	Zeolite, being overprinted by spots of fine grained carbonate	-	Spherule carbonate	Predominant	-	-	Decrease	Pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR. Carbonate spots overprints zeolite alteration in feldspars.
C	1151.800	**47-74**	**1-1: WPAR (C/Z)**	Low (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, iron hydroxide, mafic carbonates)	Trans (zeolite + carbonate), trans (carbonate)	Quartz: weak W-EX + weak B-EX	Restricted within mbsz	Zeolite, overprinted by spots of fine grained carbonates.	-	Spherule carbonate, minor ribon zeolite	Common	Kink bands are remaining in less altered biotite	-	decrease	Pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR. Zeolite coexists with carbonate, but does not coexist with mafic carbonate in vein.
C	1152.743	**48-16**	**1-1: WPAR (C)**	Low (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, iron hydroxide, zeolite aggregates, foliated)	Trans (carbonate), trans (zeolite), zeolite veins are overprinted by iron hydroxide mbsz.	Quartz, feldspar: weak W-EX	Restricted within mbsz	Rare carbonate spots	-	small amounts of thin ribon carbonate, zeolite	Rare	Kink band	-	Sightly decrease	Pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR.
C	1152.769	**48-17**	**1-1: WPAR (C)**	Low (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, iron hydroxide, fine-grained mafic carbonate)	Trans (carbonate thin vein)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Sericite, Spots of fine grained carbonates	-	Small amounts of thin ribon zeolite	-	Kink band	-	Sightly decrease	Pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR.
C	1153.213	**48-23**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, carbonate, zeolite)	Trans (carbonate thin vein), trans (zeolite thin vein)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Zeolite, Spots of fine grained carbonate	-	Ribon zeolite, Ribon and spherule carbonate	Common	Kink band	-	Sightly decrease	Pseudomorphs	Lost	Beneath the D shear zone. Coexisting type WPAR.
C	1154.167	**48-33**	**1-1: WPAR (C)**	-	Host framework texture, cracks	Trans (carbonatethin vein)	Quartz, feldspar: weak W-EX	-	Sericite, spots of fine grained carbonate	-	Ribon zeolite, Ribon and spherule carbonate	Common	Kink bands in some grains	-	Sightly decrease	Almost grains are pseudomorphs	Extremely decrease	Beneath the D shear zone. Coexisting type WPAR.
C	1155.094	**48-50**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (zeolite, self-crushed fragments, carbonate)	Trans (carbonatethin vein), trans (zeolite thin vein)	Quartz: weak W-EX + weak B-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite replaced , spots of fine grained carbonate	-	Ribon zeolite, Ribon and spherule carbonate	Rare	Kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between the D/E shear zones. coexisting type WPAR. More feldspars are replaced to zeolite close to mbsz.
C	1155.270	**48-54**	**0-1: WPAR (C/Z) (Bundary between Fine/coarse grained granitic rocks)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (zeolite, self-crushed fragments, calsite)	Trans (carbonate thin vein), trans (zeolite thin vein)	Quartz: weak W-EX + weak B-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite replaced , spots of fine grained carbonate in some grains.	-	Ribon zeolite, Ribon carbonate	Rare'	Kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. More feldspars are replaced to zeolite close to mbsz.
C	1156.277	**48-70A**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (zeolite, carbonate, self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate	-	Ribon zeolite, Ribon carbonate	Rare	Kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between E/F shear zones. Coexisting type WPAR. Strange crystal growth is observed around brecciated grain.
C	1156.277	**48-70B**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (zeolite, carbonate, self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate in some grains.	-	Ribon zeolite, Ribon carbonate	Rare	Kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. Zeolite was cut by carbonate veins.
C	1156.512	**49-1**	**0-1: WPAR (C/Z)**	N/C	Host framework texture, cracks, 1. mbsz (zeolite, self-crushed fragments, carbonate), 2. mbsz (fine-grained self-crushed fragments, zeolite, carbonate)	1.trans (zeolite), 2. trans (carbonate)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate	-	Ribon zeolite, spherule carbonate	Rare	Hydration softening and kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. Zeolite (predominant) are cut by carbonates.
C	1156.785	**49-5**	**0-1: WPAR (C/Z)**	Low (mbsz)	Host framework texture, cracks, mbsz (zeolite, self-crushed fragments, carbonate)	1.trans (zeolite), 2. trans (carbonate)	Quartz: W-EX + B-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate in some grains.	-	Ribon zeolite, spherule carbonate	Rare	Hydration softening and kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. Zeolite (predominant) are cut by carbonates.
C	1156.923	**49-6**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture (in fine grained part), cracks, mbsz (self-crushed fragments, zeolite, carbonate)	1.trans (zeolite), 2. trans (carbonate)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Zeolite, spots of fine grained carbonate in some grains.	-	Ribon zeolite, spherule carbonate	Rare	Hydration softening and kink bands in some grains	-	Sightly decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. Zeolite (predominant) is cut by carbonate.

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C	1156.923	**49-7A**	**3-3f: Ultracataclasite (Z)**	Moderate	Random fabric: matrix (ultrafine-grained self-crushed fragments? + zeolite?) + clast (self-crushed fragments + zeolite + mafic carbonate), cracks, mbsz (dark brown fine-grained material + self-crushed fragments, foliated), mbsz (foliated mafic carbonate + self-crushed fragments)	Trans (carbonate), trans (zeolite)	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	No pseudomorphs	Lost	Between D/E shear zones. 1 cm thick ultracataclasite zone, dominated by self crushed fragments. Zeolites are cut by carbonates. Coexisting type ?
C	1156.923	**49-7B**	**3-3f: Ultracataclasite (Z)**	Ultracataclasite zone moderate	Random fabric: matrix (ultrafine-grained self-crushed fragments? + zeolite?) + clast (self-crushed fragments + zeolite + mafic carbonate), cracks, mbsz (dark brown fine-grained material + self-crushed fragments, foliated), mbsz (foliated mafic carbonate + self-crushed fragments)	Trans (carbonate), trans (zeolite)	N/A because of ultrafine grain sizes	Predominant	N/A because of ultrafine grain sizes	-	-	-	-	-	Lost	No pseudomorphs	Lost	Between D/E shear zones. 1 cm thick ultracataclasite zone, dominated by self-crushed fragments. Zeolites are cut by carbonates. Coexisting type ? Some aggregates of fine grained mafic carbonate preserves flow texture.
C	1157.354	**49-11A**	**1-1: WPAR (C)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed clasts, carbonate, hydlaulic brecciation), mbsz (self-crushed fragments)	Trans (carbonate), trans (zeolite)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Spots of fine grained carbonate	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening	Some spherule carbonates are released into cracks	Decrease	Small numbers of pseudomorphs	Lost	Between the D/E shear zones. Carbonate predominant WPAR. Carbonates overprint zeolites.
C	1157.354	**49-11B**	**1-1: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments, zeolite, carbonate, ultra fine-grained layer present within it)	Trans (zeolite), trans (carbonate)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Zeolite in some grains, spots of fine grained carbonates	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening	In mbsz	Decrease	Small numbers of pseudomorphs	Lost	Between D/E shear zones. Coexsisting type WPAR (Zeolitepredominant). Carbonates overprints zeolites.
C	1158.002	**49-20**	**1-1/2-1 boundary: Cataclasite**	Moderate (boundary mbsz)	Host framework texture is barely preserved, mbsz (self-crushed fragments, mafic carbonate)	No cracks	Quartz, feldspar: W-EX	Predominant	Spots of fine grained carbonates	-	Small amount of spherule carbonate	Common	predominant hydration softening	Distinct arrangements parallel to shear surface	Extremely decrease	Small numbers of pseudomorphs	Lost	Between the D/E shear zones. Cataclasites with hydration softening. Altered (softened) biotites are arranged along the shear surfaces.
C	1160.345	**49-63**	**1-1: WPAR (Z)**	N/C	Host framework texture, cracks, mbsz (self-crushed fragments, zeolite, aggregates of utlrafine-grained materials (possibly zeolite))	Trans (zeolite), trans (carbonate)	Quartz: W-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite in some grains, spots of fine grained carbonates	-	Ribon zeolite, Ribon carbonate	Common	some grains show hydration softening along the mbsz	-	Decrease	Small numbers of pseudomorphs	Lost	Between the D/E shear zones. Zeolite type WPAR.
A	1161.507	**50-4**	**1-2: WPAR (C/Z)**	Moderate (mbsz)	Host framework texture is barely prezerved, cracks, mbsz (self-crushed fragments, carbonate, zeolite)	Trans (carbonate), trans (zeolite)	Quartz: weak W-EX + B-EX, feldspar: equant	Restricted within mbsz	Zeolite in some grains, scattered grains of stilpnomelane ?	Change color into grayish white (chlorite ?) in some grains	Spherule carbonate, ribon zeolite	Common	Hydration softening	-	Decrease	Small numbers of pseudomorphs	Lost	Between the D/E shear zones. Coexisting type WPAR. Carbonates overprints Zeolites.
A	1162.366	**50-13**	**1-1: WPAR (C/Z)**	High (mbsz)	Host framework texture, cracks, mbsz (zeolite, small amounts of self-crushed fragments, carbonate vein)	1. trans (zeolite), trans (carbonate)	Quartz, feldspar: weak W-EX	Restricted within mbsz	Replacement of zeolite is predominant, spots of fine grained carbonates	-	Spherule carbonate, ribon zeolite	Common	Hydration softening	-	Decrease	Pseudomorphs	Lost	Between D/E shear zones. Coexisting type WPAR. Most vein are composed of zeolites. Carbonates overprints Zeolites.
A	1164.048	**50-33**	**1-1: WPAR (Z)**	Low (mbsz)	Host framework texture, cracks, mbsz (zeolite, small amounts of self-crushed fragments, ultrafine grains layer)	1. trans (zeolite), trans (carbonate)	Quartz: W-EX, feldspar: weak W-EX	Restricted within mbsz	Zeolite in some grains, scattered grains of stilpnomelane ?	-	Spherule carbonate, ribon zeolite	Common	Hydration softening	Small amounts of fragmented grains in mbsz	Decrease	Pseudomorphs	Lost	Between D/E shear zones. Zeolite type WPAR.
A	1168.456	**51-31**	**1-1/3-3 boundary: Ultracataclasite (C/Z)**	High (mbsz)	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained zeolite + small amounts of fine-grained carbonate) + clast (self-crushed fragments + carbonate + zeolite), cracks, mbsz (dark brown fine-grained material, self-crushed fragments, mafic carbonate, foliated)	Trans (carbonate), trans (zeolite)	Clast quartz: W-EX, feldspar clasts: a few residual grains show weak W-EX	Predominant	N/A due to few residual grains	-	-	-	-	-	Lost	No pseudomorphs	Lost	Between D/E shear zones. 1 cm thick ultracataclasite zone, dominated by self-crushed fragments. Zeolites are cut by carbonates. Coexisting type ? Mbsz containing mafic carbonate shows distinct flow textures cutting ultracataclasite zone.
A	1170.665	**52-2**	**0-1: WPAR (C)**	-	Host framework texture, cracks	Trans (carbonate thin vein)	Quartz / feldspar: weak W-EX	-	Spots of fine grained carbonates	-	Ribon carbonate, ribon zeolite	Common	Kink bands in some grains	-	Slightly decrease	Pseudomorphs	Lost	Between the D/Eshear zones. Weak carbonate type WPAR.
A	1173.652	**52-31**	**1-1: WPAR (Felsite vein) (C/Z)**	-	Host framework texture, cracks	Trans (carbonate thin vein), trans (zeolite thin vein)	Quartz / feldspar: weak W-EX	-	Replacement of zeolite is predominant in some grains	-	Spherule carbonate, ribon zeolite	Common	Hydration softening	-	Decrease	Pseudomorphs	Lost	Above the E shear zone. Felsite veins in weak carbonate type WPAR. Veins are overprinted by carbonate veins.
A	1174.648	**52-39**	**1-1: WPAR (C/Z)**	High (mbsz)	Host framework texture, cracks, mbsz (zeolite, self-crushed fragments)	1. trans (zeolite), trans (carbonate)	Quartz / feldspar: weak W-EX	In some part within the mbsz	Zeolites in some grains.	-	Spherule carbonate, ribon zeolite small amount of	Common	Hydration softening	-	Decrease	Pseudomorphs	Lost	Above the E shear zone. Carbonate type WPAR. Carbonates overprints zeolites.
A	1175.459	**53-3**	**1-1: WPAR (C/Z)**	-	Host framework texture, cracks	Trans (zeolite), trans (carbonate)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	-	Zeolite in some grains, small amounts of sericite	-	Spherule carbonate, ribon zeolite small amount of	Common	Hydration softening	-	Decrease	Pseudomorphs	Lost	Above the E shear zone. Weak coexisting type WPAR. Feldspars are dominantly altered to zeolite.
A	1179.039	**53-47**	**3-3/2-2 boundary: Ultracataclasite part (MC)**	High	Random fabric: matrix (ultrafine-grained self-crushed fragments + fine-grained mafic carbonate + dark brown fine-grained material (layered texture) + small amounts of foliated clay) + clast (self-crushed fragments)	No vein	Clast quartz: W-EX, feldspar: N/A due to few residual grains	Predominant	N/A due to few residual grains	-	-	-	-	-	Lost	Pseudomorphs	Lost	Ultracataclasites in E shear zone. Mafic carbonate type.
A	1180.776	**54-8**	**1-1: WPAR (Z)**	Moderate (mbsz)	Host framework texture, cracks, mbsz (zeolite, self-crushed fragments, fine-grained carbonate)	Trans (zeolite), trans (carbonate)	Quartz: weak W-EX, feldspar: equant	In some part within the mbsz	Zeolites in some grains, minor spots of fine grained carbonate, most of grains are not altered.	-	Ribon zeolite in some grains	-	Weak hydration softening	-	Decrease	Pseudomorphs	Lost	Lower part of E shear zone. Weak zeolite type WPAR.

Appendix Results of microtextural observations of fault rocks under the optical microscope.

A	1181.854	**54-20**	**1-2: WPAR (C/Z)**	High (mbsz)	Host framework texture is barely preserved, cracks, mbsz (zeolite matrix + zeolite, aggregates of self-crushed fragments, pores filled with ultrafine-grained zeolite (?))	Trans (carbonate), trans (zeolite)	Quartz: weak W-EX + B-EX, feldspar: weak W-EX	Restricted within mbsz	Replacement of zeolite is predominant.	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening	Some spherule carbonates are released into cracks	Extremely decrease	Small numbers of deformed pseudomorphs	Lost	Between E/F shear zones. Coexisting type WPAR. Pores exist filled with ultrafine grained zeolite.
A	1183.121	**54-32**	**0-1: WPAR (C)**	-	Host framework texture, cracks, mbsz (heald, self-crushed fragments)	Trans (carbonate)	Quartz: weak W-EX, feldspar: equant	Restricted within mbsz	Minor carbonate spots, small amounts of sericite, grains with scattered small hornblende present.	-	Ribon zeolite, Ribon carbonate	Small amounts	-	-	Almost no decrease	About half of hornblends are altered to pseudomorphs	Decrease	Between the E/F shear zones. Carbonate type WPAR (fresh occurrence, close to host rock). Distinct halo exisits in biotite metamictization by allanite.
A	1183.306	**54-35**	**2-1: WPAR (C/Z) (with veins filled with self-crushed fragments)**	High (mbsz)	Host framework texture, cracks, mbsz (self-crushed fragments (with fragmented biotites), cataclasite)	Trans (carbonate), trans (zeolite)	Quartz / feldspar: weak W-EX	Restricted within mbsz	Zeolite, Spots of fine grained carbonate	-	Spherule carbonate, ribon zeolite	Common	Hydration softening	-	Decrease	Pseudomorphs	Lost	Upper part of F shear zone. Coexsisting type WPAR acompanied by veins filled with brecciated grains, just above minor fault breccia zone.
A	1183.764	**54-39**	**2-2: Fault breccia (C) Hydraulic brecciation with carbonate matrix**	Moderate	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained zeolite + fine-grained carbonate) + clast (self-crushed fragments + carbonate + zeolite), carbonate matrix hydraulic brecciation texture, cracks.	Trans (carbonate)	Quartz / feldspar: weak W-EX	Predominant	Predominant zeolite	-	Spherule carbonate, ribon zeolite	Predominant	Hydration softening	-	Extremely decrease	Small numbers of pseudomorphs	Lost	Upper part of F shear zone. Carbonate type fault breccia zone. Hydraulic brecciation texture with carbonate matrix overprints fault breccia with zeolite matrix.
A	1185.645	**55-10**	**0-1: WPAR (C/Z)**	-	Host framework texture, cracks.	Trans (zeolite), trans (thin veins of carbonate)	Quartz / feldspar: weak W-EX	-	Carbonate spots in some grains	-	Ribon carbonate	Small amounts	Kink bands in some grains	-	Not decrease	Pseudomorphs	Lost	Upper part of F shear zone. Coexisting type WPAR.
A	1186.478	**55-22**	**2-2: Fault breccia (Z)**	Moderate	Random fabric: matrix (fine-grained zeolite + fine-grained self-crushed fragments + fine-grained carbonate) + clast (self-crushed fragments + zeolite + fine-grained carbonate aggregates), zeolite matrix hydraulic brecciation, cracks.	Trans (zeolite), trans (carbonate)	Quartz: W-EX, subgrains are formed in some clasts, feldspar: weak W-EX	Predominant	Zeolite, stilpnomelanes (?) are formed in the clasts within a shear zone	Change color into grayish white (chloritization?)	Spherule carbonate	Predominant	Predominant hydration softening	Some hydrated, softened biotites are relaeased into cracks	Extremely decrease	One grain of deformed pseudomorph	Lost	Middle part of F shear zone. Zeolite type fault breccia. Feldespars are replaced by secondary stilpnomelane (?).
A	1187.438	**55-29**	**2-2: Fault breccia (C)**	High	Random fabric: matrix (fine-grained self-crushed fragments + fine-grained carbonate + fine-grained zeolite) + clast (self-crushed fragments + zeolite + fine-grained carbonate aggregates), hydraulic brecciation texture with carbonate matrix overprints fault breccia with zeolite matrix. Weak flow texture develops where mafic carbonate dominates, cracks.	Trans (carbonate), subgrains are formed in some grains.	Quartz: W-EX, feldspar: weak W-EX	Predominant	Zeolite, spots of fine grained carbonate	Change color into grayish white (chloritization?)	Spherule carbonate	Predominant	Predominant hydration softening	Some hydrated, softened biotites are relaeased into cracks	Extremely decrease	Small numbers of pseudomorphs	Lost	Middle part of F shear zone. Carbonate type fault breccia.

淡路島，野島平林 NIED 掘削コアの 1,140m 深度破砕帯における精密断層岩分布解析

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要　旨

兵庫県南部地震（1995，M＝7.2）に伴い，淡路島北西部に地震断層（野島断層）が出現した．科学技術庁防災科学技術研究所では，野島平林において断層貫通掘削を実施し（掘削深度 1,822 m），1,140 m，1,300 m，および 1,789 m の 3 深度の破砕帯を含むコアを回収した．本論文では，1,140 m 破砕帯の断層岩分布様式，およびそれらの微小構造の観察結果を記載している．これらの解析を通して，次の諸点が明らかとなった．(1)掘削深度 1,140 m において，野島断層の破砕帯の幅は 70 m 以上となっており，6 つ剪断帯（A～F 帯）を含んでいる．(2) D 帯は 12.1 m の幅を持ち，中軸部の D_2 亜帯に薄いシュードタキライト様の岩石を挟むことから，主要なすべり面は D_2 亜帯の基底面（掘削深度 1,141.24 m）である可能性が高い．(3) A～F の各剪断帯に共通する特徴として，中軸部のウルトラカタクレーサイト/シュードタキライト帯に水酸化鉄/苦鉄質炭酸塩型の変質作用が認められ，その上盤，下盤側に，炭酸塩，沸石に富む水圧破砕組織が，それぞれ認められることが挙げられる．上盤の変質作用は，CO_2 を溶存した表層水が，下盤は Na^{2+} に富む流体が，それぞれ深く関与し，間震期（interseismic period）に岩石-水反応を起こした結果，形成されたものであると考えられる．また，水圧破砕組織は，地震発生時に超静水圧(super hydrostatic)状態が発生したことを示唆している．中軸部のウルトラカタクレーサイト/シュードタキライト帯は，地震時に大変位をもたらした摩擦発熱帯（friction/heat generation zone）である可能性が高い．一方，この帯は，上盤と下盤の岩石-水反応を隔絶していることから，間震期においていは，流体のバリアとして機能していたものと考えられる．

キーワード：兵庫県南部地震，野島断層，断層岩分布，変形・変質微小構造